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Orville Adelbert Derby, for many years one of the associate editors of this *Journal*, was born at Kelloggsville, New York, on July 23, 1851, and died by his own hand at Rio de Janeiro, Brazil, on November 27, 1915.

After graduating at the high school, Derby entered Cornell University in 1869, taking what was then called the scientific course. While he was yet a Freshman, however, he became so interested in geology and was such a promising student that he was selected by Professor Charles Fred Hartt, then professor of geology at Cornell, to accompany him on a trip to Brazil in the summer of 1870. That was the first trip made to Brazil by Derby; it determined both his career and the whole course of his life. On his first voyage he visited Pernambuco, and made the first considerable collection of fossils ever made at Maria Farinha, a locality that has since been looked upon with especial interest by students of the Mesozoic history of South America.

In the summer of 1871 he went to Brazil with Hartt again, this time visiting the Amazon valley and making an important collection of Carboniferous fossils from the limestones at Itaitúba on the lower Tapajos River.

In 1873 he graduated from Cornell University with the degree of Bachelor of Science, and the year following he continued his geological studies for the Master's degree, which he received in June, 1874. His thesis was "On the Carboniferous Brachiopoda of Itaitúba, Rio Tapajos," and was published as No. 2 of Vol. I of the *Bulletin of Cornell University*, Ithaca, 1874. That was Derby's first publication on the geology of Brazil, and it is not only a valuable paper in itself, but it is especially interesting in view of subsequent developments. The Itaitúba fossils were in compact limestone, but as they were silicified they could be obtained in satisfactory form only by dissolving away the surrounding rock —a long and tedious process which would have thoroughly discouraged most young men of Derby's age. The spires of many of the specimens of these brachiopods have seldom been surpassed for delicacy and perfection.

The art of illustration was far from being so well developed in those days as it is now, and we thought ourselves very fortunate in being able to make and use the crude photographs with which that paper was illustrated.

In 1873 Derby was appointed instructor in geology at Cornell, and in the summer of 1874 Professor Hartt made arrangements to go to Brazil again. Leave of absence was obtained, Derby was placed in charge of the work of instruction in the department, and in September, 1874, Hartt went to Brazil again, taking Branner with him as his only assistant and going by way of Europe. It is often said that Hartt went to Rio on the invitation of the Brazilian government or of the Emperor D. Pedro II. As a matter of fact he went entirely on his own responsibility and without invitation from anyone, but with the idea of inducing the Brazilian government to establish a geological survey under his direction.

Arriving in Rio de Janeiro, he at once devoted all his energies to interesting the leading men in a geological survey of the empire, and by the end of the year the survey was authorized and provided for, and O. A. Derby, Richard Rathbun, and E. F. Pacheco Jordão were named as assistants of the new "Commissão Geologica do Imperio do Brasil." In December, 1875, Derby reached Rio de Janeiro and began his work under the government. He held this

position less than two years, for through a change of ministry the survey was abolished in 1877, and Hartt died in Rio that same year. Shortly after the suspension of the survey, however, Derby was given a position in the National Museum at Rio as curator in charge of geology, a position which enabled him to continue his studies on the geology of Brazil, and, to a certain extent, to preserve the results of the work of the extinct survey. He remained in the museum until 1886 when he was made state geologist of the Brazilian state of São Paulo.

The establishment of the São Paulo survey was a step of great importance to geological science in Brazil, for Derby's knowledge of and interest in the geology of the country as a whole enabled him to grasp more firmly the geological problems of that particular state, and at the same time he became and remained, up to the time of his death, the leading authority on the geology of Brazil. He was state geologist of São Paulo until 1904, when he resigned.

In 1907 a new federal geological service was provided for, and Derby was made its chief, a position he held during the rest of his life.

The first edition of Branner's *Geologia Elementar*, a work prepared especially for Brazilian students of geology, was thus dedicated: "To Orville A. Derby, who has devoted his life to the study of the geology of Brazil, and has done more than anyone else to solve its many problems, this work is affectionately dedicated." This is a brief and mild statement of Derby's great services to Brazil and to the science of geology, without mentioning his many other services to science and to that country.

First and last Derby was a paleontologist. He had no fondness for administrative work; he was but little interested in structural geology or in its methods; he was forced by circumstances into some acquaintance with microscopic petrography; but his interest in paleontology was genuine, deep, and all-comprehensive. From all the cares of office and the worries of life he found relief and happiness in boxes of poorly preserved fossils that most paleontologists would have put away as not worth while.

It was chiefly to this interest of his in paleontology that we owe Dr. C. A. White's *Contributions to the Paleontology of Brazil*,

published at Rio in 1887; John M. Clarke's *Trilobites of the Ereré and Maecuru Sandstones*, Rio, 1896; *Upper Silurian Fauna of Rio Trombetas*, Rio, 1899; *Devonian Mollusks of the State of Pará*, Rio, 1899; and *Devonian Fossils of Paraná*, Rio, 1913. Besides these excellent works there are many smaller papers on paleontology that cannot be mentioned here, and there still remains unpublished an important volume by D. S. Jordan on the Cretaceous fossil fishes of Ceará.

During the last eight years Derby gave much of his time to the study of *Psaronius* and its relationships. The last of his published papers was on the stem structure of *Tietea singularis*, and appeared in the *American Journal of Science* for March, 1915, pp. 251–60.

Because he had to undertake work in regions but poorly supplied with maps, one of his first and most important duties, when he became state geologist of São Paulo, was the inauguration of topographic work. This work was intrusted to Horace E. Williams, an able and energetic young American to whom the state of São Paulo and the scientific world are indebted for an excellent series of topographic maps on a scale of one to 100,000, to say nothing of his explorations of the western portions of São Paulo, his work on the Serra da Canastra, etc.

Derby's own list of publications on the geology of Brazil numbers 125 papers. Naturally they embrace a wide range of subjects. Ten of his papers relate to the geology and genesis of the Brazilian diamonds. One of these, on the geology of the diamond and carbonado region of the state of Bahia, was the first publication to give an idea of the geology of that little-known district.

He became interested in the early cartography of Brazil, and published a number of papers on that subject.

As an author and as a scientific reasoner he was an extremely cautious man, so much so that the word "hedge" was constantly on his lips both for his own guidance and as a warning to his assistants.

The last evening I spent in his rooms at Rio de Janeiro he referred to this personal trait, and remarked that it had prevented his marrying—that he was too cautious to take the risk. This cautiousness of his was probably the real reason for some of the

long delays in publishing his results, delays which led to the tying up of his own results and those of his assistants. Without doubt he hoped that the delays would enable him to put everything beyond question and to make his reports final and complete instead of preliminary and tentative. But the delays were prolonged from year to year until his assistants became discouraged and the government more or less exasperated at the lack of practical results for such great and long-continued expenditures. It was probably this long delay that finally led to his resignation as state geologist of São Paulo.

Derby never felt obliged to show results. After he had been state geologist of São Paulo for ten or twelve years, and had published next to nothing on the geology of that state, I asked him point blank, and with some feeling, where his results were. He replied: "They are in my head." We had to change the subject. But the important fact behind his delays is that the geology of São Paulo is difficult and involves problems that he had not been able to settle to his own satisfaction, and he was unwilling to commit himself definitely to paper and thus lay himself open to adverse criticism.

It seemed unfortunate for Brazil, for himself, and for the cause of science that he was unable to bring himself to take an active interest in the economic geology of the country. But his first and only interest in geology was in geology as a pure science. To him a fossil was a thing of beauty, of interest and value, and a joy forever, but a mine or an industry was, after all, only an industry whose main object was money-getting.

Derby was a man of unlimited grit. When once he decided upon a course of action nothing turned him to the right or to the left. His whole life is a demonstration of his power to make good in spite of obstacles that would have been insurmountable for most men—his determination to be the leading authority on the geology of Brazil, cost what it might.

How many of us would have lived for forty years, in a foreign country, cut off, as he was, from all personal contact with the geologists of the world at large and from the people of his own race and from his own family? And yet, from the time he went to Rio

in 1875 to the day of his death he visited the United States only twice. One of these visits was in 1883 when he spent three months at Washington; the other was in 1890 when he attended the meeting of the American Association for the Advancement of Science at Indianapolis.

When the Commissão Geologica was abolished in 1877 the rest of us took to our heels. Not so Derby; he was not to be stampeded by a simple lack of funds or of employment; he meant to save the results of the work of Hartt and of his colleagues, and, in so far as it could be done, he did it.

Personally Derby was one of the kindest-hearted and most affectionate men I have ever known. His last dollar was at the service of his friends, and his right hand knew nothing of the kind deeds done by his left. The beggars in the streets found him their easiest victim.

He was held in the highest esteem in the community in which he lived. He stood for uprightness and honorable dealing, and he was never the willing tool of designing adventurers. For many years he has been justly regarded as the leading geologist in South America, and his standing is due, not to the fact that there are but few first-class geologists in South America, but to his ability and to his excellent work.

In 1892 he was awarded the Wollaston prize of the Geological Society of London, while his distinguished services led to his being made one of the associate editors of the *Journal of Geology* and to his election to membership in various learned societies in different parts of the world. He was a frequent contributor to the *American Journal of Science* and to this *Journal*.

A list of his papers on the geology of Brazil up to 1909 is given in the *Bulletin of the Geological Society of America*, XX, pp. 36–42. To that list should be added thirteen additional titles of papers that have appeared since its publication.

TYPES OF PRISMATIC STRUCTURE IN IGNEOUS ROCKS[1]

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The question of the cause of columnar or prismatic jointing in igneous rocks was thought to have been satisfactorily settled by the writings of Thomson, Mallet, Bonney, Iddings, and others, until it was reopened recently by the investigations of several French physicists. As the subject seems to be in need of further discussion and experimental study, I have brought together observations on several hypotheses of prismatic jointing, hoping to show that the study of these structures may yield much more precise information than is now available as to the original conditions of occurrence of the igneous rocks in which such structures are found.

CRYSTALLIZATION HYPOTHESIS

The first hypothesis as to the origin of prismatic structure which had any experimental or observational basis was that of Gregory Watt,[2] and may be entitled the "crystallization hypothesis." Watt, in 1804, observed that a large mass of basalt which he had melted down in a reverbatory furnace crystallized radially from centers which were fairly regularly spaced in a horizontal plane; the intersections of these radially growing fibrous bundles formed a network of hexagonal partings through the mass, leading Watt to the conclusion that this manner of crystallization, by its vertical extension upward from the base of a mass of basalt, must have been the cause of the prisms found in the Giant's Causeway, Fingal's Cave, and elsewhere.

[1] Presented before the Geological Society of Washington, April 28, 1915.

[2] Gregory Watt, "Observations on Basalt, and on the Transition from the Vitreous to the Stony Texture," etc., *Phil Trans.*, 1804, pp. 279–314. Watt also explains clearly the contractional origin of such structures as mud and starch prisms.

This explanation seems to have been satisfactory to many of the earlier authors of geological treatises,[1] but before many years had passed doubts began to arise as to whether this process could have been an efficient cause of the numerous cases of columnar structure which began to accumulate in geological literature as travel became more extensive and observations multiplied. James Thomson[2] in 1863 urged that contraction of a homogeneous mass was a sufficient cause for all columnar structure, and that the hypothesis of crystallization from centers was unnecessary and improbable. Mallet[3] discussed the contraction hypothesis in detail, showing how it would account, in his opinion, for all of the structures found in columnar rocks. Bonney,[4] Iddings[5] and others have followed the same lines of argument.

CONTRACTION HYPOTHESIS

The radial-contraction hypothesis is still the explanation generally accepted by the textbooks, and perhaps applies in the majority of cases of prismatic structure. But a much more complete discussion of this hypothesis than has yet been published could be profitably made, for there has been no attempt at any quantitative application of it to actual occurrences. It has served hitherto simply as a qualitative explanation. The relation of the size, shape, curvature, jointing, and other properties of the columns to the original temperature, viscosity, and rate and manner of cooling of the rock is capable of more exact definition.

For instance, the time factor in cooling in its relation to the elastic properties of the rock does not seem to have been considered

[1] More or less vaguely associated with this definite hypothesis was the idea of a "concretionary force" which is frequently referred to. The idea that columns might be due to the mutual compression of actual spheroids of lava (now understood as "pillow" lava) was also more or less confused with the crystallization hypothesis. Watt's idea of the matter seems to have been perfectly clear, but Mallet, for instance, misunderstands Watt's "mutual compression of spheroids" to mean actual compression (*Phil. Mag.*, L [1875], 221–24); the words "mutual interference of radially growing spheroids" state Watt's meaning more clearly.

[2] *Brit. Assoc. Rep.*, 1863, Abstract, p. 89.

[3] *Phil. Mag.* (4), L (1875), 122–35, 201–26.

[4] *Quar. Jour. Geol. Soc.*, XXXII (1876), 140–54.

[5] *Amer. Jour. Sci.*, XXXI (1886), 321–31.

in previous discussions. If the mass is cooling slowly, the crystallized shell may be able to adjust itself by a slow movement to the stress produced by contraction, so that the strain does not for some time pass a given value. If the cooling is rapid, on the other hand, the strain may be rapidly raised through the inability of the mass to flow as rapidly as the stress is applied. Under conditions of rapid cooling, therefore, the temperature at which the stresses become sufficient to produce rupture will be higher than under conditions of slow cooling.[1]

Another point concerns the conditions of rupture. Published discussions of formation of columns by contraction have tacitly assumed that the condition of rupture is that the *extension* shall exceed a certain limiting value. This is only one out of several possible conditions of rupture. Various hypotheses have been proposed by physicists (limiting tension, limiting positive or negative strain, limiting shear), of which the best founded experimentally is that of Tresca and Darwin, according to which rupture occurs when the maximum difference of the greatest and least principal stresses reaches a certain limiting value.[2] Although the acceptance of this condition of rupture as the fundamental one does not simplify the problem of calculating the actual physical magnitudes of temperature, temperature gradient, stress, and strain in any given case, yet it should permit a more complete analysis of the kinds of structure that will result from different conditions of cooling. Such an analysis is, however, beyond the scope of the present article.

CONTRACTION OF PHYSICALLY HETEROGENEOUS MATERIAL

Prismatic structure is very common in materials which are heterogeneous as regards their state of aggregation (such as mud and wet starch), that is, in which solid matter is suspended in or mixed with a liquid. It is a question whether the formation of a prismatic structure in such materials is strictly comparable with most cases of contraction prisms in igneous rocks. The principal

[1] The above-mentioned effect of the rate of cooling is quite distinct from the commonly recognized effect, which appears in the *temperature gradient* away from the surface of the cooling mass.

[2] Love, *Theory of Elasticity*, 1906, p. 119.

difference is in the strength of the materials. Very considerable stresses may accumulate in a glassy or crystalline rock before rupture occurs, and when it does occur, the crack extends suddenly a considerable distance into the mass. A layer of wet mud, on the other hand, accumulates practically no stresses, as the forces of cohesion and liquid surface tension to be overcome are very small. The cracks therefore form much more gradually, and grow little by little as desiccation proceeds. They have even been observed to form under water,[1] probably as a result of freezing and melting.[2]

It is possible that some basalt prisms have been formed in the same way as the slowly formed mud cracks, by the slow shrinkage of a material which is partly solid and partly liquid, for the normal course of crystallization of an igneous rock consists in the separation of certain portions as crystals while the remainder stays liquid until a lower temperature is reached. It has been commonly observed, however, that the boundaries of contraction columns frequently cut across the crystals of the rock, showing that solidification was practically complete before the crack formed.

An example of prismatic, although not columnar, structure produced in this manner is probably to be found in the "apparent sun-crack structure in diabase," described by Wherry as occurring in the upper surface of the great diabase sill of Pennsylvania, west of Philadelphia.[3] He explains it as due to contraction jointing followed by the penetration of still liquid material into the cracks from below. At first sight this occurrence has some of the characteristics of prismatic structure due to liquid convection accompanied by segregation, but a re-examination of the structure by Dr. Wherry and the author in May, 1915, showed that the angles and polygons

[1] Moore, *Am. Jour. Sci.*, XXXVIII (1914), 101–2.

[2] Mud cracks may also belong to the other types of columnar structure. Where the deposit is very fine grained and homogeneous, the walls of the columns may show the feathery patterns characteristic of a fractured solid, resulting from breaks (either sudden or slow-growing) which occurred when the material was nearly dry, and indicating the existence of tensional stresses. On the other hand, a prismatic structure of apparently convectional origin has been observed by Guillaume (*Soc. Franc. Phys., Bull. Seances*, 1907, pp. 50–51) in mud flows in sub-Arctic regions.

[3] E. T. Wherry, "Apparent Sun-Crack Structures and Ringing-Rock Phenomena in the Triassic Diabase of Eastern Pennsylvania," *Acad. Nat. Sci., Philadelphia, Proc.*, LXIV (1912), 169–72.

are those produced by contraction, not by convection (see p. 225). A photograph of the occurrence is shown in Fig. 1. An examination by Wherry of the cross-section of one of the small "dikes" shows that it has an irregular boundary, that it grades off without a sharp break into the surrounding rock, and that it is more coarsely crystalline than the surrounding material. It appears to be, therefore, a case of prismatic structure due to contraction in physically heterogeneous material, and quite distinct from the usual type of contraction prisms. Dr. N. L. Bowen, of this laboratory, informs me that he has seen a similar structure in the upper surface of a diabase sill north of Lake Superior.[1]

CONVECTION HYPOTHESIS

E. H. Weber[2] described in 1855 a phenomenon observed by him on microscope slides on which a solid was being precipitated from alcohol-water mixtures. The liquid was observed to circulate and to divide itself up into regular polyhedral cells. A similar phenomenon was observed by James Thomson[3] in 1882, in a soap solution. It remained for the French physicist Bénard,[4] in 1900, to make a really thorough study of the subject, and his experiments have brought out a number of new and interesting facts.

A polygonal structure is easily produced in a layer of liquid which is shallow in comparison with its horizontal extent, and which is losing heat from its upper surface or is gaining heat from its lower surface. If the top surface is cooler than the bottom, then the colder and denser liquid at the top tends to sink and the warmer bottom layer to rise, and convection currents must be set up. If the conditions are uniform and constant, a *steady state of flow* of some kind must ultimately be set up. In a flat liquid sheet of indefinite extent this state of flow must take the form of parallel rising and descending currents, and these will flow with minimum

[1] Canada, Bur. Mines, *Ann. Rep.*, XX (1911), 125–26.

[2] *Pogg. Ann.*, XCIV, (1855) 452–59.

[3] *Phil. Soc. Glasgow, Proc.* XIII, (1882), 464–68. Thomson recognized the similarity of the pattern to that of the Giant's Causeway.

[4] H. Bénard, *Les tourbillons cellulaires dans une nappe liquide*, etc., thesis, Paris, 1901; *Rev. gén. Sci.*, XI (1900), 1261–71, 1309–38.

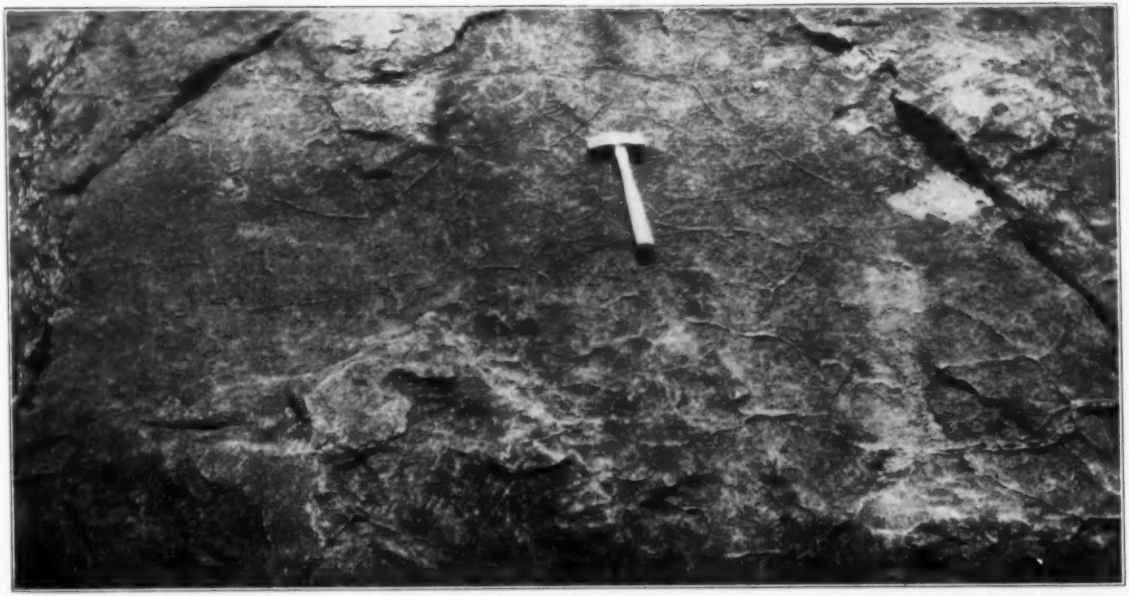

FIG. 1.—Prismatic structure due to contraction in physically heterogeneous material. Top of diabase sill west of Philadelphia, Pennsylvania.

friction only when they divide the liquid into hexagonal cells, as can be shown by the same line of argument as is used to prove that a uniform shell, under tension due to its own contraction, breaks with minimum energy expenditure when it divides into hexagons.

Fig. 2 is a cross-section of one of these hexagonal cells, showing how the currents rise in the middle of each prism and flow down at

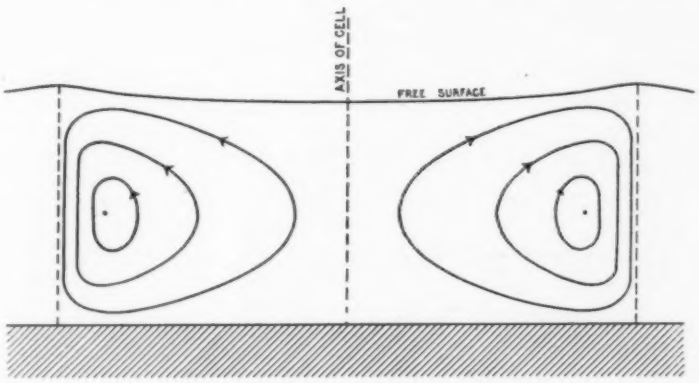

FIG. 2.—Cross-section of a hexagonal cell, showing how the currents rise in the middle of each prism and flow down at the boundaries.

the boundaries. The contour of the surface of the liquid is exaggerated in the figure, but the relief is quite sufficient to permit the structure of the circulating liquid to be observed by various optical methods. Fig. 3 shows three examples of these structures in a melted wax, taken under different conditions of temperature and thickness and before the final steady state of circulation had been attained.

A state of subdivision into irregular cells of from four to seven sides is attained in a few minutes, even in a viscous oil. These cells then join and subdivide repeatedly until finally, if the conditions are constant, a perfect system of hexagonal cells is produced. Even when the liquid is originally in motion, convection cells form which show little or no trace of the original direction of movement of the liquid as a whole.

Waxes and oils were used for most of Bénard's experiments, because at his working temperatures of 100° and lower the requisite conditions as to viscosity and low volatility could best be obtained with these materials. By suspending in them finely powdered substances such as graphite or lycopodium, Bénard was able to show visually and to photograph the cells produced, without the aid of special optical devices.

As is to be expected, the dimensions of the cells depend upon the thickness of the liquid layer, the temperature difference between top and bottom, and the viscosity and temperature of the liquid.

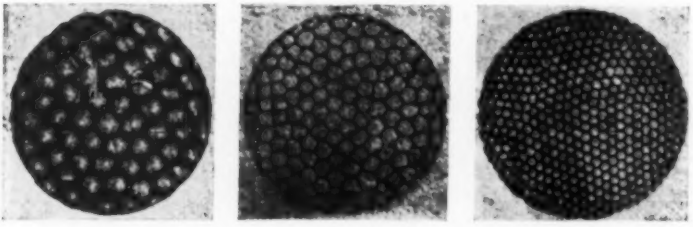

FIG. 3.—Three examples of hexagonal cells formed in a melted wax, taken under different conditions of temperature and thickness and before the final steady state of circulation had been attained.

In a given liquid at a given temperature, and at a constant temperature difference, the ratio of diameter to height is found to be constant. Other laws governing the form and size of the cells were found by Bénard, but it is unnecessary to discuss these in detail.

Following Bénard, Dauzére[1] in 1907 showed that crystallization in salol and wax mixtures begins on the boundaries of the convection cells. A mixture of beeswax and stearin, on solidifying, separates spontaneously into hexagonal prisms coinciding with the original convection cells. In pure stearin, also, crystallization begins at the corners of the cells. In every case the cells leave a permanent record of their existence in the crystallized solid, although in some cases the structure is quite invisible, and only

[1] C. Dauzére, *Jour. physique*, VI (1907), 892–99; VII (1908), 930–34; *Assn. franc. av. sci.*, 1908, pp. 289–96.

appears when the wax is bent. Dauzére pointed out the strong probability that certain symmetrical columns in Auvergne have been due to convection in the basalt in which they are formed.[1]

In a horizontal sheet of molten rock which has come to rest after extrusion or intrusion it is obvious that we have some at least of the conditions necessary for the formation of convection cells. If the cells succeed in leaving any permanent record of themselves when the sheet solidifies, then subsequent contraction may bring out the structure by cracking the rock along the boundaries of the cells.

In general there are two ways in which the convection cells might impress themselves on the crystallized rock. In the first case the axes of the liquid convection cells and of the solid prisms are coincident. Bénard found that a finely powdered substance which is heavier than the liquid tends to gather on the bottom of the vessel in little heaps situated on the axes of the convection cells, giving an appearance from above of uniformly spaced round spots. A floating substance, on the other hand, gathers along the boundaries of the cells at the surface. A substance in suspension gathers within the interior portion of the closed curves of Fig. 2, so that the liquid shows transparent both on the axes and along the boundaries of the cells. In a mixture, therefore, in which different crystalline phases are separating at different temperatures, a certain amount of segregation is to be expected, and the solid prisms will coincide with the convection cells.

In a substance which crystallizes as a unit, on the other hand, whether it be a pure substance or a considerably undercooled mixture, prisms may be formed without segregation. Bénard observed that in spermaceti the crystallization began at the corners of the cells. In pure stearin Dauzére found that crystallization beginning at centers on the cell boundaries extended uniformly in all directions until the growing cylindrical groups intersected to form prisms. It is evident that in this case the prisms will not coincide with the convection cells, but will nevertheless be symmetrical and regularly spaced.

[1] C. Dauzére, *Assn. franc. av. sci.*, 1908, pp. 436–38; also Longchambon, *Bull. Soc. Geol. Fr.*, XIII (1913), 33–38.

It is of interest to note that this convection-crystallization hypothesis explains the original observation of Watt on the formation of columns in a cooling artificially melted basalt mass (see p. 215). He accounted for his columns on the assumption that they were produced by the mutual interference of radially growing crystal bundles, uniformly spaced in a horizontal plane. Why the crystallization centers should be uniformly spaced he was unable to say. The existence of convection prisms in the still liquid basalt provides the missing link in the series of phenomena. Crystallization may have begun at the axes of the convection prisms where a few early separating crystals had collected, or at the corners as observed by Bénard; in either case the crystallization centers would be uniformly spaced horizontally.[1]

If liquid convection is really the cause of all or any of the familiar naturally occurring basaltic columns, then it is important to know what criteria will help to decide the question in a given case. Furthermore, a systematic examination of natural columns will throw light on their history, whatever may be their mode of origin. What are the important characteristics of a given occurrence which should be observed in the field?

CHARACTERISTICS OF CONTRACTION AND CONVECTION PRISMS

1. *Attitude.*—The original attitude of columns formed by convection should be vertical, or very nearly so. Contraction columns, on the other hand, are usually perpendicular to a cooling surface; irregular conditions of cooling, furthermore, may cause them to curve in a great variety of ways.

2. *Dimensions.*—Convection columns should be much wider, in proportion to their length, than contraction columns, which are commonly very long and narrow. The columns at Murols described by Dauzére are 1.5 to 2 m. wide and 5 to 10 m. high; those measured by O'Reilly in the Giant's Causeway are 0.4 to 0.5 m. in width; the Causeway columns vary from 3 to 25 m. in total height. Scrope describes columns near La Queuille as much as 5 m. in diameter, and 10 m. or less in height.[2] The common contraction

[1] See Longchambon, *Bull. Soc. Geol. France*, XIII (1913), 33–38.

[2] *Volcanoes of Central France*, London, 1858, p. 136.

columns, on the other hand, are usually about 0.2 m. or less in diameter; their length is often 20 m. without a joint, and their total length may be over 40 m. It should be noted, however, that the composition of the rock may have a considerable effect on the size of columns under given conditions of cooling, the more salic rocks forming larger columns than the more femic rocks.

3. *Shape of cross-section.*—Convection columns, if perfect, should all be hexagonal. The more uniform the conditions have been, the greater the proportion of hexagons; in any case, the hexagonal sections will be in the majority. Seven-sided figures will be common, produced by the trunkation of one angle of a hexagon; pentagons will also occur frequently, by the elimination of one side of a hexagon. But three- and four-sided figures will be very rare.

In contraction columns, on the other hand, pentagons are likely to be the prevailing type, and four-sided figures are fairly numerous, while hexagons become less important. This distribution of polygons arises from the fact that a mass cracking under the stresses of its own thermal contraction, although theoretically it should break into perfect hexagons of equal area, actually tends to yield by the formation of master-cracks which are then joined up by the formation of shorter cracks.[1] An example of thermal contraction prisms on a large scale is seen in the soil polygons of Arctic regions; a map of a set of these polygons, in a recent article by Leffingwell,[2] shows clearly the contraction-type fissures described above.

The relative frequency of polygons in some of Bénard's artificial convection cells,[3] in the Giant's Causeway,[4] and in a columnar dike[5] is shown in Table I.

[1] "The rock may rather be said to be divided into numerous perpendicular fissures, than to be prismatic, although the same picturesque effect is produced."—Lyell, description of Torre del Greco.

[2] E. De K. Leffingwell, *Jour. Geol.*, XXIII (1915), 653.

[3] The photograph used for this computation was one taken while the liquid was cooling and the polygons were undergoing gradual changes, leading to the formation of 5- and 7-sided figures. Under steady conditions of heat flow the cells were hexagons almost without exception.

[4] J. P. O'Reilly, *Roy. Irish Acad. Trans.*, XXVI (1879), 641–734.

[5] A. Geikie, *Ancient Volcanoes of Great Britain*, illustration, p. 459.

Bénard[1] has recently shown photographically the identity of pattern between his convection cells and the cross-section of the basalt columns of the flow of Estreys (Haute-Loire), and has also pointed out the qualitative differences between this pattern and that produced by contraction.

TABLE I

COMPARATIVE FREQUENCY OF POLYGONS (PERCENTAGE)

No. of Sides	Artificial Cells	Giant's Causeway		Columnar Dike
		Along a 50-Meter Line	Within Measured Area	
3	0	0	0	5.2
4	5.5	2.0	3.5	28.4
5	36.3	30.7	24.8	43.1
6	45.2	47.1	50.5	20.7
7	12.7	19.6	19.2	2.6
8	0.3	0.6	2.0	0
Total number counted	292	153	206	116

4. *Frequency of angles.*—The angles of convection columns should approximate to 120°, while contraction columns will have a large proportion near 90°. While the frequency of angles is a much more logical criterion than the frequency of different polygons, it is much more difficult to apply on account of the large number of angular measurements to be made. Such a series was made with great care by O'Reilly on the Giant's Causeway, and I have summarized his results in Table II. O'Reilly's deduction from his

TABLE II

FREQUENCY OF ANGLES IN 206 POLYGONS OF THE GIANT'S CAUSEWAY

Range	No. of Occurrences	Range	No. of Occurrences
64° to 75°	9	115° 30′ to 125°	238½
75° 30′ to 85°	19½	125° 30′ to 135°	236½
85° 30′ to 95°	56½	135° 30′ to 145°	143
95° 30′ to 105°	103½	145° 30′ to 155°	18½
105° 30′ to 115°	215	155° 30′ to 175°	5

measurements was that the form of the columns had been governed by the principal angles of the constituent minerals of the basalt, a view which has not met with general acceptance.

[1] *Compt. rend.*, CLVI (1913), 882–84.

5. *Difference in composition and texture between the axis and the periphery of the columns.*—Obviously, no variation whatever should appear in contraction columns. If the columns are due to convection, however, there might or might not be a differentiation, depending upon whether the rock crystallized practically as a unit, or whether it crystallized in stages which permitted of segregation in the convection cells (see p. 223).

In 1914 Dr. H. S. Washington, of this laboratory, examined, in the museum of the University of Catania, a polished section of a column from one of the prehistoric basaltic flows of the Mount Etna region, and observed no variation of texture across the section. From their shape and manner of occurrence, these columns at Etna would seem to be due to pure contraction, and no variation is to be expected.

On the other hand, evidence is not lacking in geological literature of what seems to be a differentiation between the border and axis of some basalt columns. Scrope, in his description of the volcanoes of central France, states that "occasionally (as for example at La Tour d'Auvergne, in the Mont Dore), the columns show a cylinder of compact black basalt within a prismatic case of lighter colour and looser texture, a segregation of dissimilar matter having accompanied the concretionary action."[1] Delesse[2] made in 1858 an interesting comparison of the density of the interiors and exteriors of a variety of columns, the results of which are shown in Table III. Here again a difference between the interior and exterior is indicated in some of the columns, though not in all. Unfortunately the source of the samples which showed small differences is not stated; it may be that they are columns of the narrow contraction type. Delesse took care to assure himself that the differences were real and were not due to weathering of the columns, but it is not impossible that the differences are really due to weathering, since he had not the modern microscopic facilities for examining the individual minerals in thin section.

[1] *Volcanos*, 1862, p. 100. In speaking of "concretionary action" Scrope seems to be referring to the rather vague hypothesis of columnar structure which prevailed at the time (see note, p. 216).

[2] Delesse, "Variations dans les roches se divisant en prismes," *Compt. rend.*, XLVII (1858), 448–50.

The regularity and symmetry of the columns of the Giant's Causeway suggests the convectional origin. It seemed of interest, therefore, to examine a polished cross-section of one of these columns for evidence of differentiation. Through the kindness of Dr. G. P. Merrill, of the United States National Museum, a polished section was cut for us from a Giant's Causeway column in the Museum, and also one from a column from near Bonn on the Rhine.

TABLE III

DIFFERENCE IN DENSITY BETWEEN AXIS AND SURFACE OF BASALT COLUMNS (DELESSE)

	Density		Difference of Density
	Center	Outside	
			Per Cent
Trachyte, Iceland	2.494	2.478	0.64
Trachyte, Isle Ponce	2.469	2.439	1.21
Phonolite, Isle Lamlash	2.541	2.509	1.26
Trap, Antrim	2.911	2.857	1.85
Basalt	2.930	2.933	−0.10
Basalt	3.030	3.030	0.00
Basalt	2.924	2.916	0.27
Basalt	3.053	3.030	0.75
Basalt	3.044	3.008	1.18

The Bonn column was five-sided, with a maximum cross dimension of 18 cm. The cross-joint near which the section was cut showed fracture lines radiating from one corner, and the joint passed straight across. What appeared to be an inclusion about 16 mm. in diameter showed near the center, and another of similar size seemed to have been cut in two by one face of the column. A sharp weathered zone 3 mm. wide showed clearly, but no other difference between center and border appeared.

The Giant's Causeway column was also five-sided, with a maximum cross-dimension of 37 cm. The section was cut near the convex side of a shallow ball-and-socket joint; the fracture of this joint seemed to have radiated from the *center*, not from any point of the border. The rough surface gave an appearance of finer grain at the border than at the center. On the polished face, however, no such gradation was visible. There was a sharp weathered zone 3 mm. wide, inside of which was a zone varying from 6 to

22 mm. in width, with an ill-defined wavy border. This also may have been due to weathering. Within the central eighth of the area appeared 5 amygdules from 2 to 4 mm. in diameter, and filled with a greenish opalescent mineral. Five others, from 1 to 2 mm. in diameter, appeared in the remaining seven-eighths of the area, none being closer than 25 mm. to the border. The section therefore offers no decisive evidence of a differentiation, although markedly different in character from the Bonn column.

6. *Types of cross-jointing in the columns.*—A differentiation due to convection might be expected to affect the cross-joints of the columns. The peculiar convex-concave or cup-and-ball joints are seldom found in irregular narrow columns of the typical contraction type, and might have some direct connection with a convection structure. Another type of cross-jointing of columns is the "platy" variety, which is sometimes very regular; its origin has not been satisfactorily explained from the physicist's standpoint.

Certain special peculiarities of the cross-jointing may also have to do with the mode of origin of the columns. For instance, James Thomson[1] observed that the symmetrical concave-convex joints of columns from the Giant's Causeway have their origin in a small spot or knob which lies at or near the axis of the column, and differs in texture and hardness from the rest of the rock; from this origin the crack has spread outward, as shown by the radial fracture lines. This same form of fracture has just been described above, as occurring in the National Museum's specimen from the Giant's Causeway. Dauzére mentions the same peculiarity in the columns at Murols, and compares it with the core (*noyau*) which forms in the convection prisms of his wax-salol mixture.

There seems to be good foundation for the opinion that some sort of original structure is responsible for the spheroidal weathering of columns, and that it is not due solely to the rounding off of jointed blocks by weathering, as some have claimed. Thus Bonney cites numerous examples of spheroids formed from columns which showed no cross-joints whatever.[2] Whether these latent spheroids have any connection with the manner of growth of the column it is

[1] *Belfast Nat. Field Club, Ann. Rep.*, VII (1869), 28–34.

[2] *Quar. Jour. Geol. Soc.*, XXXII (1876), 140–54.

as yet impossible to say. Longchambon[1] suggested that the superimposed spheroids are due to a breaking up of long liquid convection cells into a number of shorter ones, each with its own local circulation, but there is no experimental evidence to support this.

7. *Irregularities of faces of prisms.*—Some basalt prisms show the "feather-patterns" characteristic of fractures in homogeneous solids. Their occurrence points strongly to a purely contractional origin. They have been observed in the joint planes of slates, and have been made the subject of an interesting study by Woodworth.[2]

SURFACE STRUCTURE PRODUCED BY INTERNAL EXPANSION

In addition to the prismatic structures produced by contraction and convection or by convection combined with crystallization and contraction, still another type needs to be considered, namely that due to *expansion*.

The accompanying photograph of a polygonal structure in a cement briquette (Fig. 4) is an illustration of the formation of this structure by internal expansion. This sample, which was kindly furnished us by Mr. A. A. Klein, of the Bureau of Standards in Pittsburgh, was made from a cement which contained free lime; this by its hydration and absorption of carbon dioxide from the air has expanded and destroyed the briquette.

It is possible that the "weather-crack" structure on the surface of diabase bowlders is likewise caused by internal expansion. Wherry[3] has shown that there is no visible difference in texture underlying these weather-cracks. Expansion of the surface by hydration has been assumed as the cause of the structure; but this would produce *compression* in the surface, accompanied by the formation of shells (as indeed often occurs), whereas the "weather-crack" structure is one indicating *tension*. It is necessary for hydration to proceed into deeper portions of the rock before tension

[1] *Soc. Geol. France, Compt. rend. somm.*, 1912, pp. 181–83; *Bull.*, XIII (1913), 33–38.

[2] *Proc. Boston Soc. Nat. Hist.*, XXVII (1896), 163–83. For an extended study of these feather fractures in glass and metals see Ch. de Fréminville, "Recherches sur la fragilité; L'éclatement," *Rév. metallurgie*, 1914; also Mallock, *Proc. Roy. Soc.*, A, LXXXII (1909), 26–29.

[3] *Loc. cit.*

is set up in the surface; the cracks then produced are soon widened by solution. A photograph of an excellent example of this type of structure in diabase is given in Fig. 5. Internal expansion may also account for the prismatic surface structure of "bread-crust bombs," although this remains to be proved.

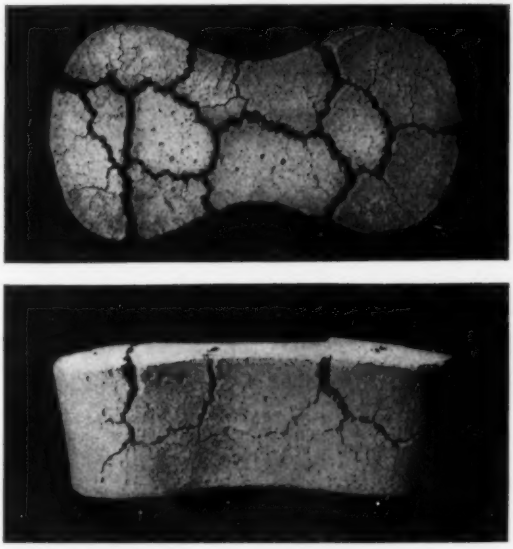

FIG. 4.—A polygonal structure in a cement briquette, caused by internal expansion.

SUMMARY

From the physical standpoint, several types of prismatic structure in igneous rocks can be distinguished. The first and most common is due purely to thermal contraction in the crystallized rock; examples are numerous and familiar. A subordinate type of contraction structure is produced when the contraction and separation occur while the magma is still partly crystalline and partly liquid; this type is illustrated by an occurrence in a diabase sill in eastern Pennsylvania.

FIG. 5.—"Weather-crack" structure on the surface of a diabase bowlder

The second general type is produced by convectional circulation of the magma while still liquid. The cells so produced persist until solidification begins, and may leave a record in the rock either by causing segregation in the cell walls and axes, or by originating regularly spaced centers of crystallization. The experimental and observational data on the occurrence of this type in igneous rocks are suggestive, but cannot yet be said to amount to decisive proof.

A third type of prismatic structure is produced by internal expansion. It has been produced artificially, and is offered as the explanation of the "weather-crack" structure seen in diabase bowlders.

In the study of these structures, the following field observations are those which will be of greatest interest in the further study of the problem: (1) attitude of prisms, (2) their diameter and length, (3) frequency of four-, five-, six-, and seven-sided polygons, (4) frequency of angles (especially 90° and 120°), (5) variation, if any, of composition and texture in the cross-section, (6) types of cross-jointing (platy, concave or convex, spheroidal), (7) spacing of cross-joints, (8) peculiarities of cross-joints (e.g., whether cracked from center or from borders), (9) degree of irregularity in sides of prisms, (10) other peculiarities, such as tapering, partial longitudinal jointing, etc.

The primary object of this discussion is to call attention to the possibilities of the prismatic structure of a given rock body as an index of its conditions of formation. Quantitative data on columnar structures are very scarce; yet quantitative measurements must precede quantitative deductions. We wish to know the temperature of the rock when it was intruded or extruded; its viscosity when it began to cool and when it began to crystallize; the amount and kind of gases which it released; if extrusive, the climatic conditions under which it cooled; if intrusive, the properties of its inclosing strata at the time of intrusion. These and other facts are deducible only from the present properties of the rock, among which its prismatic structure will prove of great importance.

Equally necessary with the field data are experimental studies of the structures produced in a cooling magma under conditions

that can be controlled and measured. Such experiments will require the melting and handling of larger quantities than it has been customary to use for laboratory experiments, but the difficulties ought not to prove serious. Even in the absence of such experimental data, much can be learned from a careful field examination of prismatic and columnar structures.

ELLIPSOIDAL LAVAS IN THE GLACIER NATIONAL PARK, MONTANA[1]

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The paper by Capps on "Some Ellipsoidal Lavas on Prince William Sound, Alaska,"[2] recalls to my mind a similar occurrence which I visited in 1907. The locality is now so accessible and the flow is so clearly subaqueous in character that a brief description of it may be of interest. Its outcrop appears in the ridge (Shepard Mountain) northeast of Flattop Mountain, Glacier National Park, Montana, and the features described are in that portion of the bed which overlooks the Shepard Glacier. The lava, to which the name Purcell lava has been commonly applied, interrupted the sedimentation of a flat-lying, greenish argillite which forms the uppermost part of the Siyeh formation of the pre-Cambrian. This argillite lies in normal position, and the portions above and below the lava bed are macroscopically identical.

The Purcell lava is approximately 150 feet thick on Shepard Mountain and can be traced for miles to the southeast, north, and northwest. It is composed of six or more successive flows, each of uneven and more or less ropy surface, separated by small and more or less local accumulations of shale. The lower 25 or 30 feet of the flow is composed of a conglomeration of dense, homogeneous, spheroidal masses averaging 1 to 2 feet in diameter. They preserve their shape in the lower layers, being separated from each other by chert or drusy cavities, and many individuals have displaced considerable portions of the mud upon which they were rolled or shoved, even to the extent of complete burial. The bottom of the flow is therefore exceedingly irregular. Toward the top of this bed the individual spheroids yield more or less to the

[1] Published by permission of the Deputy Minister of Mines.

[2] *Jour. Geol.*, XXIII (1915), 45–51.

pressure of their fellows, and they unite to form an upper surface of moderate unevenness. The upper part of the entire flow is composed of a bed about 20 feet thick, which, though massive in character, is very porous. Vesicles are common near the base of several of the individual flows in the lower portion of the lava.

On Mount Grinnell, 10 miles to the southeast, Finlay[1] gives the thickness of the lava bed as 42 feet, but does not mention the ellipsoidal masses which Daly later describes from the same locality.[2] Finlay records the discovery of five genetically connected dikes on Flattop Mountain close to the localities where the ellipsoids are present. Elsewhere, though the lavas reached the surface through numerous widely scattered dikes, ellipsoidal structure has not been recorded. This period of igneous activity has been described[3] as having genetically connected extrusive and intrusive phases, and it is interesting to note that strata, upon whose upper subaqueous surface lava was being extruded, should have been able, at a depth of only 600 feet, to accommodate themselves to the essentially contemporaneous intercalation, along single planes, of intrusive sills scores of square miles in extent.

This flow seems to afford an excellent opportunity for determining the value of certain criteria for distinguishing (1) subaerial from subaqueous flows, and (2) the top from the bottom of subaqueous flows. Here the normal attitude of the flow and its including sediments is unquestionable, and the bottom of the bed in which the ellipsoidal structure is developed is far more uneven than the top, an observation which lessens the importance of one of the criteria advanced by Capps. Furthermore, the silting up of cracks in the surface of the flow would seem more natural than the upward penetration, into cracks several feet in height, of mud sufficiently resistant to flatten the bases of individual ellipsoids. That the latter is true for the Prince William Sound locality[4] merely illustrates the difficulty of obtaining competent and unconflicting criteria.

[1] *Bull. Geol. Soc. America*, XIII (1912), 350.

[2] *Memoir Geol. Survey Canada*, No. 38, Part I (1912), p. 217.

[3] Daly, *ibid.*, pp. 218–20.

[4] Capps, *Jour. Geol.*, XXIII (1915), 49.

So far as the Glacier National Park exposure of the Purcell lava is concerned, the following criteria would seem to indicate the bottom of a subaqueous flow: (1) discreteness of the basal spheroids and their relative competence to resist mashing; (2) comparative unevenness, with reference to the top; (3) the irregular displacement of the underlying shale by the basal spheroids; and (4) the presence of vesicles near the base of the individual flows. Criteria indicating the top are: (1) the common ropy structure; (2) more or less complete fusion of the individual spheroids; (3) comparative evenness, with reference to the bottom; (4) silting up of hollows in the top by strata whose laminae parallel those of the adjacent strata; and (5) the absence of vesicles in the upper portions of the individual flows.

The flow under discussion covers an area hundreds of square miles in extent, and while its extrusive character has been recognized by various observers, the ellipsoidal structure has only been found at the localities described. It may have been subaqueous in places, subaerial in others (the Siyeh argillites are abundantly ripple-marked and sun-cracked in places), but many lines of evidence seem to prove its subaqueous character at the locality described, and indicate that ellipsoidal structure is a competent criterion of subaqueous extrusion.

THE ORIGIN OF RED BEDS

A STUDY OF THE CONDITIONS OF ORIGIN OF THE PERMO-CARBONIFEROUS AND TRIASSIC RED BEDS OF THE WESTERN UNITED STATES

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PART II

CONDITIONS OF DEPOSITION OF RED CLASTIC SEDIMENTS: MODERN TYPES

Seven distinct types of partly or wholly clastic modern red sediments have come to the attention of the writer, some of which, however, are closely related. The occurrence of each one of these types and its application to the Red Beds of the western United States is discussed in the following paragraphs.

Red clay of the deep-sea bottom.—This material is invariably very fine-grained, it contains little or no terrigenous matter of any kind, and it accumulates very slowly indeed, so that a thickness of it comparable to the total thickness of shales in any series of the western Red Beds is practically inconceivable. Nearly every part of all the series included in the Red Beds group exhibits incontestable evidence of shallow-water deposition, while the oceanic red clays are exclusively abysmal deposits. Such arguments could be multiplied almost indefinitely; it is quite clear that deep-sea red clay is not related to our problem in any way whatsoever.

Stream deposits derived from pre-existing Red Beds.—This type of deposits is illustrated by the flood-plain deposits of the Red River of the South, in Texas, Oklahoma, and Louisiana. This type cannot be dismissed so easily, for there are yet in existence masses of pre-Cambrian red sediments within the possible drainage areas tributary to some of the areas of the Red Beds. One objection to this source for the ferruginous matter of the Red Beds is that there were other sources for the sediments in question, nearer than

the pre-Cambrian series, and that much of the material of the Red Beds is known to have been derived from other rocks.

Arkosic stream deposits.—These are illustrated by deposits of limited extent in and downstream from the region occupied by the Sherman granite of Wyoming, which weathers to a coarse pink gravel, owing its color to a high content of undecomposed pink orthoclase. It is obvious that much the greater part of the color of the Red Beds is not due to pink feldspar; but in some of the very arkosic sediments of the Cutler and Dolores formations, and probably elsewhere, this is an element not to be ignored.[1]

Stream deposits deriving their coloring matter from ferruginous residual soils.—The fourth type of modern red sediments is exemplified by the continental portion of the deposits of the lower Amazon, and by smaller deposits in some of the rivers of the United States. Russell says:

> Each grain [of sand in residual soils left by the decomposition of crystalline rocks in the southern Appalachian Piedmont] is coated with a thin shell having a brownish or red color. Prolonged washing fails to remove this superficial coating, a fact which is well illustrated by the color of the sands deposited by the streams of Virginia and the Carolinas in the regions underlaid by crystalline rocks.[2]

Russell appears to assume that all of the ferric oxide produced by the decay of the crystalline rocks of this area is attached to grains of other minerals in this way. That which fills interstices between grains of sand in the final deposit,[3] as distinct from that which occurs in coatings on the grains, probably persisted independently, however, and was transported as a fine sediment like clay.[3]

The relation between surface weathering of the Piedmont crystalline rocks and the color of the Newark clastics in the neighboring areas, as developed by Russell, is very much the same as a relation recently advocated by Beede[4] between weathering of lime-

[1] Cf. Whitman Cross, Telluride Folio (No. 57), *Geol. Atlas of the U.S., U.S. Geol. Survey*, 1899, p. 2.

[2] I. C. Russell, "Subaerial Decay of Rocks," *U.S. Geol. Survey Bull. No. 52*, 1889, p. 14.

[3] See p. 164, this volume.

[4] J. W. Beede, "Origin of the Sediments and Coloring Matter of the Eastern Oklahoma Red Beds," abstract in *Bull. Geol. Soc. America*, XXIII (1912), 723–24.

stones and the color of the Red Beds of eastern Oklahoma. He says:

> The coloring matter is thought to have been derived from the solution of the 7,000 or 10,000 feet of pre-Carboniferous limestone which formerly covered the Arbuckle-Wichita Mountains and much of the surrounding region. The solution of the limestone furnished optimum conditions for the oxidation of its iron content, as it does at the present time in the limestone regions of the Mississippi Valley, southern Europe, West Indies, and elsewhere. Moreover, the solution of the pre-Carboniferous limestones and the conglomerates of the Arbuckle-Wichita region now in progress produces a red residuum practically indistinguishable from Red Beds sediments. The red granites, red porphyries, and other crystalline rocks of the region under discussion contributed their shares of material to the Red Beds.[1]

The Red Beds of the Grand Canyon section are underlain by the famous Redwall limestone, and limestones underlie the Red Beds practically throughout the Plateau province and in the San Juan region. Areas in Colorado of history similar to that of the Arbuckle-Wichita region, in that highlands existed there after the earlier Paleozoic limestones were deposited, and during Red Beds times, may well have played the same part in the central Rocky Mountain region that Beede assigns to the Arbuckle-Wichita uplift in Oklahoma. The existence of such highlands is demonstrated by the great conglomerates in the Colorado Red Beds.[2] Various other land-masses which contributed material to the sediments of the Red Beds[3] may have been quite as efficient as the Arbuckle-Wichita highlands in producing residual soils stained by ferric oxide.

It is evident from the foregoing discussion that stream deposits deriving their coloring matter from ferruginous residual soils are probably of no little importance in the Red Beds, and may constitute a major part of the series of sediments included under that term.

Terrigenous marine clastics.—The fifth type of modern red sediments is illustrated by deposits in the Atlantic Ocean off the mouth of the Amazon River.[4] This is an exceptional occurrence,

[1] Beede, *op. cit.*

[2] See pp. 244-245.

[3] See pp. 245-246.

[4] John Murray, *Challenger Reports, Deep Sea Deposits*, 1891, p. 234.

as most terrigenous red muds lose their color on entering the sea. A vivid description of this process of loss of color in the case of certain rivers in Nova Scotia is given by Dawson, as follows:

> This harbour [Pictou] receives the waters of three rivers and several smaller streams, which in times of flood carry into it large quantities of reddish mud, which sometimes discolours the whole surface. This mud, with similar sediment from the shore of the harbour, is deposited in the bottom, and there undergoes a remarkable change of colour. A portion of old mud recently taken from the bottom is of a dark grey colour, and emits a strong smell of sulphuretted hydrogen. . . . . The iron of the red clay has entered into combination with sulphur, and this is probably obtained from the sulphates contained in the sea-water, by the deoxidizing influence of decaying vegetable matter . . . . which grows abundantly on the mud flats. . . . . In some parts of the deposit forming in Pictou harbour, the vegetable matter which caused the change of colour is so completely decomposed that no visible fragments of it remain.[1]

The chemical action of marine organic matter is summarized by Clarke in part as follows: "Decomposing organic matter reduces the sulphates of sea-water to sulphides, which by reaction with carbonic acid yield sulphuretted hydrogen. Bacteria also assist in the process."[2]

The interbedding of marine limestones with Red Beds shales in the Texan section is consistent with an origin for the shales similar to that of the semi-oceanic sediments from the Amazon River. The interbedding of gray and green strata with red ones in certain of the Red Beds series indicates an oscillation of dominance between oxidizing and deoxidizing conditions, such as might be caused at the margin of the sea or in the waters of an inclosed basin by variations in the rate of sedimentation or in the abundance of organic matter. The marine type of deposition of red sediments is not to be neglected, therefore, in an attempt at reconstruction of the conditions of origin of the Red Beds; though the complete absence of marine fossils from other parts of this group of sediments, together with independent proof of the continental origin of most of the group, shows that the marine type cannot be of more than subordinate importance.

[1] J. W. Dawson, "On the Colouring Matter of Red Sandstones and of Greyish and White Beds Associated with Them," *Quar. Jour. Geol. Soc. London*, V (1848), 29.

[2] F. W. Clarke, "The Data of Geochemistry," 2d ed., *U. S. Geol. Survey Bull. No. 491*, 1911, pp. 136-137.

Deposits of desert lakes or playas.—For an example of the sixth type of present-day red sediments, deposited under water in desert lakes or playas, we turn to Chinese Turkestan. The following description, by Huntington, relates to the northern extremity of the bed of Lop Nor, near the southern base of the Kuruk-Tagh or Dry Mountains: "Beyond the fatiguing plain of salt [dry bed of the dwindled lake Lop Nor] we found easy traveling for a time. A fantastic red plain, the soft, dry bed of an older expansion of the lake, glittered with innumerable gypsum crystals."[1]

Here we have a recent deposit of gypsum (or, more properly, selenite), in which the crystals presumably are imbedded in a red clay or mud. The relations here described could be duplicated by many minor deposits of gypsum in the Red Beds of the western United States. Farther out toward the center of the lake floor occur the purer non-clastic sediments, which in the case of Lop Nor are described as salt beds. The coloring matter of the clays probably was derived, as in the two preceding types of modern red sediments, from the decay of rocks on the neighboring uplands.

Red dune sands.—The seventh and last type differs from all the others in being an eolian deposit. Red dune sands are exceptional rather than the rule in the desert regions of today, but they occur in sufficient abundance to warrant attention. Their most striking occurrence is in the Nefood or Red Desert of Northwestern Arabia. The following quotation is from Palgrave's narrative of a journey taken in 1862: "We were now traversing an immense ocean of loose reddish sand, unlimited to the eye, and heaped up in enormous ridges, ... undulation after undulation, each swell two or three hundred feet in average height."[2]

The extreme breadth of the Nefood is about 150 miles, its greatest length about 400 miles.[3]

Huntington mentions "an almost absolutely barren area of reddish or yellowish sand dunes, from ten to a hundred or more feet

[1] Ellsworth Huntington, *The Pulse of Asia* (Boston and New York: Houghton Mifflin Co.), p. 254.

[2] W. G. Palgrave, *Central and Eastern Arabia* (London: Macmillan, 1908), pp. 62–63.

[3] See J. A. Phillips, "The Red Sands of the Arabian Desert," *Quar. Jour. Geol. Soc. London*, XXXVIII (1881), 110–13.

high"[1] between Karakir and Keriya River, in the southern border of the Takla Makan Desert, Chinese Turkestan. Some 40 or 50 miles farther north is the district described in the following passage: ". . . . ridge after ridge of sand, fifty to one hundred feet high. . . . . Their gently sloping backs to windward were gray with a cover of rather coarse sand, while their steep fronts to leeward were pale brick-red with the fine sand of the main desert."[2]

There are in the Red Beds of the western states no sandstones of this type of such great thickness as that of the Nefood sands, yet the possibility must be recognized that there may be local sandstone members of this origin in the series. A region dry enough to admit of the production of great bodies of gypsum might easily be transgressed by shifting sands; or the two types of deposition might exist side by side, as they do today in the region of Lop Nor and Takla Makan. The coarsely cross-bedded sandstones of the Chugwater formation along the eastern base of the Wind River Range in Wyoming, for instance, will bear further investigation with this possibility in mind.

EVIDENCE OF FEATURES OTHER THAN COLOR AS TO THE CONDITIONS UNDER WHICH THE RED BEDS WERE DEPOSITED

The wide range in grain shown by the Red Beds of various parts of the West, and the varying quantity of non-clastic sediments in the group, show that a variety of conditions existed in this region during the time the Red Beds were accumulating, as is to be expected from the great extent of the group. What the varying relations were will be pointed out as accurately as possible in the following pages.

Evidence of conglomerates as to the sites of land-masses.—Conglomerates, by the pebbles which they contain, display more clearly than other sediments the source of their component materials. We can therefore determine with some confidence the sites of the land-masses which gave rise to the Red Beds, where these are conglomeratic. In southeastern Oklahoma, Beede[3] has presented facts to show that the lower Red Beds sediments were derived from

[1] Huntington, *op. cit.*, pp. 183–84.

[2] *Ibid.*, pp. 184–85.

[3] *Op. cit.*

the Arbuckle-Wichita region. Near the border of the present Arbuckle and Wichita mountains, limestone conglomerate and conglomerate of crystalline rocks dovetail into Red Beds sediments of finer grain. The limestone undoubtedly was derived from earlier Paleozoic formations, and the crystalline fragments from more ancient rocks, both of which are known to have been exposed in the uplifted region just named. Increasing thickness of sediments toward the mountains testifies to the same relation. To what distance sediments from this isolated highland may have been distributed is largely a matter of conjecture. The entire Red Beds series thins northward from this area to the northern limit of their outcrops in Nebraska, and in the same direction clastic sediments give place in part to limestones: both of which facts signify increasing distance from the source of terrigenous material. The small outlier of Red Beds in central Iowa, which probably is to be correlated with the Cimarron series of Kansas,[1] is composed chiefly of red shale and gypsum, likewise indicating relatively clear-water conditions. It would be an unwarranted assumption, however, to assume that the Kansas and Iowa Red Beds were derived wholly from the Arbuckle highlands. The greater areas of upland which probably existed in the region surrounding and including the pre-Cambrian areas of Minnesota and Wisconsin may have been important sources of material, as may also the ancient Appalachian continent of the East; but it may safely be said that their influence is not exhibited in the strata now available for study, as the influence of the Arbuckle highland so clearly is.

Similar criteria may be applied to the great conglomerates of the Fountain and Wyoming formations of the Front Range, and to those of central and southwestern Colorado. The conglomerates of the Front Range Red Beds and of the Maroon formation of the Anthracite, Crested Butte, and Tenmile districts are made up chiefly of fragments from pre-Cambrian crystallines,[2] which still

[1] Cf. F. A. Wilder, "The Age and Origin of the Gypsum of Central Iowa," *Jour. Geol.*, XI (1903), 723–48.

[2] See Whitman Cross, Pikes Peak Folio (No. 7), *Geol. Atlas of the U.S., U.S. Geol. Survey*, 1894; G. K. Gilbert, Pueblo Folio (No. 36), 1897; and G. H. Eldridge, "Description of the Sedimentary Formations," Anthracite-Crested Butte Folio (No. 9), 1894.

outcrop in wide areas in various parts of the ranges. The Maroon conglomerates include also fragments of quartzite and limestone from older sediments. The composition of these formations renders it certain that their materials were not carried far from their sources; it is therefore certain that there were highlands, and there may have been mountain ranges of no insignificant relief in various parts of Colorado during Red Beds time—which here probably was included for the most part within the Pennsylvanian and Permian periods.

The coarser beds of the Cutler and Dolores formations in southwestern Colorado show by their composition that they also were derived very largely from igneous and metamorphic terranes.[1] The studies of Cross[2] have shown that the northern part of the San Juan region itself, as well as the neighboring Uncompahgre Plateau, was exposed to erosion between early Cutler and Dolores time—at or near the beginning of the Mesozoic era. This upland may have furnished sediment to a considerable part of the plateau province to the west and southwest. Cross is of the opinion that the absence of the Red Beds on the Uncompahgre Plateau is due to post-Dolores erosion;[3] but the conglomeratic character of the Red Beds in the San Juan Mountains demands that a source for those sediments be found close at hand. In the absence of any conclusive evidence that the Red Beds ever were deposited over the plateau in question, it may be regarded at least provisionally as the probable site of that source.

The sediments of the Plateau province, on the whole, do not indicate mountainous topography in the vicinity; but their great thickness (maximum more than 5,000 feet, excluding non-clastic beds) calls for the existence of a land area contributing sediments to this region for a long period of time. Such an area may well have existed toward the south and southwest, in Mexico, southwestern

[1] See Whitman Cross and others, in the following folios of the *Geol. Atlas of the U.S., U.S. Geol. Survey:* Telluride (No. 57), 1899; LaPlata (No. 60), 1899; Silverton (No. 120), 1905; Needle Mountains (No. 131), 1905; Ouray (No. 153), 1907; Engineer Mountain (No. 171), 1910.

[2] Whitman Cross, "Stratigraphic Results of a Reconnaissance in Western Colorado and Eastern Utah," *Jour. Geol.*, XV (1907), 648–49, 654–56.

[3] *Ibid.*, pp. 648–49.

Arizona, and southeastern California, or farther north in the Great Basin, where no sediments contemporaneous with those in question are known to occur.[1] The absence of sediments between the Mississippian and the Cretaceous in the El Paso quadrangle[2] in western Texas may be due altogether to erosion following deformation at the close of the Jurassic period, but this gap in the record makes it possible that land may have existed even here during Red Beds times.

Richardson has concluded from his studies of the Black Hills Red Beds[3] that those sediments were derived chiefly from the Rocky Mountain area to the southwest and west. West of central Wyoming, the Red Beds group thickens, and the quantity of limestone and gypsum in it diminishes, continuously westward across the Idaho border, suggesting a source of sediments in that direction. The great thickness of the group all along the Wasatch Range, wherever it is exposed, extends this suggestion to include a considerable land area trending north and south from southern Idaho into central Utah.

Significance of non-clastic sediments.—The more important limestone members of the Red Beds record the existence of extensive bodies of clear and not excessively salty water during parts of the Pennsylvanian period in central Texas, in the Plateau Province, in the San Juan region, and in southeastern Wyoming; during the Permian, in the region north and east of Great Salt Lake (in the early part of the Permian, marine deposition throughout much of Wyoming, prior to the initiation of Red Beds sedimentation there), and in western Texas; and in the Triassic, in northeastern Arizona.

[1] Cf. paleogeographic maps by the following authors: T. C. Chamberlin and R. D. Salisbury, *Geology* (New York: Henry Holt & Co., 1909), II, 545; III, 3 and 62; W. B. Scott, *An Introduction to Geology* (New York: Macmillan, 1909), pp. 616, 662; Charles Schuchert, "Paleogeography of North America," *Bull. Geol. Soc. America*, XX (1909), Pls. 84–88 inclusive.

[2] G. B. Richardson, El Paso Folio (No. 166), *Geol. Atlas of the U.S. U.S. Geol. Survey*, 1909.

[3] G. B. Richardson, "The Upper Red Beds of the Black Hills," *Jour. Geol.*, XI (1903), 365–93.

The extraordinary development of gypsum in the Permian Red Beds deserves more than passing comment. In association with salt, deposits of gypsum are interpreted as indicating aridity of climate at the time of deposition, and of formation in at least partially inclosed basins by the evaporation of bodies of water not freely connected with the open sea.[1] This occurrence of gypsum, supported by independent evidences of continental origin for the Red Beds, has been the one strongest influence in establishing the idea that the red color itself is an indication of aridity. The absence of gypsum from many series of Red Beds, and its occurrence in series free from Red Beds, make it necessary to investigate the two problems on their own independent merits.

Rock salt is of relatively rare occurrence in the group of sediments under discussion. Since the saturation point of gypsum in aqueous solution is much lower than that for common salt, it is logical to suppose that the deposition of gypsum unaccompanied by rock salt signifies a condition of aridity and of continuous or intermittent supply of normal sea-water or of fresh water such as to maintain a degree of salinity more moderate, for example, than that of Great Salt Lake at present, but sufficient to cause the continued precipitation of gypsum. Such a condition might be kept up by a limited or intermittent connection between the open sea and the basin of deposition.

The relation of the gypsum and salt deposits of the West to the Red Beds proper suggests a relation similar to the relation between marine limestones and terrigenous sediments. The Rustler dolomite and the Castile gypsum of the Texan portion of the Pecos Valley give place northward to typical Red Beds with a few interbedded strata of dolomite and gypsum. May not the gypsum, as well as the dolomite, be but the complements of the red clastic sediments, deposited in the clear central waters of an inland sea, or in lagoons near or at sea-level but partly or wholly cut off from the sea; while clastic sedimentation went on nearer the shores and on river deltas or flood-plains yet nearer to the sources of sediment?

[1] Cf. Wilder, *op. cit.*

The clastics: minor structural features.—Returning to the clastic sediments, we may draw still further inferences regarding the conditions under which they were deposited, from their structural characteristics and mineral composition. Ripple-marks and mud-cracks in the majority of Red Beds sections testify to the prevailing shallowness of the water in which these sediments were laid down. Mud-cracks repeated in layer after layer, as in some parts of the Red Beds, mean complete emergence and at least partial drying, after the deposition of each stratum and before that of the next following. Shallow water means shifting currents, and these too are recorded clearly by cross-bedding in most sandstones of the series, and by rapid variation along the strike in the shaly members as well. We do not have, in the clastic portions of the Red Beds, and seldom do we find in the non-clastic members thereof, the continuity of a single type of sedimentation over wide areas and through long periods of time, which are to be expected in truly subaqueous or marine deposits. Furthermore, imperfect assortment, which is one of the universal characteristics of fluviatile deposits, is the rule in the Red Beds. The sandstones are earthy, the shales sandy, the conglomerates gritty, etc. Each of these characteristics is suggestive of subaerial conditions, and the occurrence of all of them together in the same series, and widely distributed through that series, is conclusive testimony to such an origin.

The clastics: mineral composition.—From the mineral composition of the clastic sediments we may infer something of the conditions of weathering and transportation which preceded their deposition. The high proportion of feldspar in many of the Red Beds shales and sandstones indicates a preponderance of mechanical disintegration over chemical decomposition. The abundance of undecomposed mica flakes in most Red Beds confirms this interpretation. Transportation may precede complete decomposition because of exceptional rapidity of disintegration, exceptional slowness of decomposition, or both. Rapid disintegration may be caused by such factors as high relief and great daily or seasonal range of temperature; slow decomposition by low rainfall or low temperatures. Low temperatures throughout the year explain

the slowness of chemical decomposition in polar regions; aridity explains it in the desert, where disintegration is accelerated by great daily range of temperature; and disintegration is accelerated on mountain peaks by all of the factors mentioned. Absence of vegetation, which itself is dependent chiefly on climatic factors, is unfavorable to rapid decomposition of rocks because of the important part played by organic acids in the chemical processes of weathering.

As we have seen, the occurrence of gypsum indicates aridity and high temperatures, so that we may rule out the hypothesis of Arctic conditions as applicable to the Red Beds. The coarse conglomerates in certain parts of the Red Beds are indications of high relief in certain areas and at certain times.

The occurrence of limestone conglomerate in the Red Beds of the Arbuckle-Wichita region emphasizes the predominance of disintegration over decomposition in that area, as limestone is one of the most readily decomposed of rocks. If the limestone conglomerates of the Cutler formation were detrital, it would have the same significance concerning the processes of the San Juan region; but it has been interpreted otherwise.

Evidence supplied by fossils.—It has been stated that marine limestones carrying abundant faunal remains occur in central Texas interbedded with the Permo-Carboniferous Red Beds. The significance of the relations found in this region is well summarized by Chamberlin and Salisbury, as follows:

> The oldest part of the Permian system (*Wichita formation*) indicates that the critical attitude which characterized the surface farther east during the Pennsylvanian period now affected Texas, for the beds are partly of marine and partly of fresh-water origin. These beds are succeeded by a formation of limestone (the *Clear Fork*) of marine origin, which overlaps the Lower Permian. The Upper Permian (*Double Mountain* formation) which follows indicates a reversal of relations, for much of Texas was again cut off from the ocean, and converted into an inland sea, or into inland seas, in which the phases of deposition common to such bodies of water took place. Occasional beds of limestone with marine fossils point to occasional incursions of the sea, while deposits of salt and gypsum point with equal clearness to its absence, or to restricted conditions, and to aridity of climate.[1]

[1] T. C. Chamberlin and R. D. Salisbury, *College Geology* (New York: Henry Holt & Co., 1909), p. 661.

The large and varied vertebrate fauna which has now been described from the clastic members of the Red Beds series in various parts of the Southwest[1] includes no forms requiring other than a land or fresh-water habitat, with the exception of fish remains in some of the marine beds just mentioned. In general, then, it is true that the paleontological evidence corroborates the purely stratigraphic and lithologic evidence for a continental origin for at least the greater part of the Red Beds. In certain places and at certain horizons the fossil remains, both plant and animal, are sufficiently abundant and of such types as to eliminate the possibility of extreme aridity as a continuously prevalent condition. The bone beds and petrified forests of northeastern Arizona, for instance, prove that during the time of deposition of the Shinarump group,[2] at least, there was a water supply in that vicinity sufficient to permit the support of abundant land life, both vegetable and animal. It is possible, however, that this water supply was derived from precipitation in a distant region, like the waters of the Nile delta. In the underlying Permian, which contains more salt and gypsum than the other members of the series in this district, vertebrate remains are absent. The Permian of the neighboring Kanab Plateau has yielded an extensive invertebrate fauna[3] suggesting brackish-water environment.[4]

Summary.—The most salient of the facts and inferences brought out by the foregoing discussion of the significance of features other than color as to the conditions of deposition of the Red Beds may be summarized as follows: (1) rapid erosion on land-masses of considerable relief; (2) decomposition not complete in advance of transportation; (3) sediments diminishing in thickness and in coarseness of grain away from sources of material, and clastic

[1] See especially various publications by S. W. Williston in the *Journal of Geology*, 1903–13.

[2] L. F. Ward, "Geology of the Little Colorado Valley," *Am. Jour. Sci.*, 4th Ser., XII (1901), 401–13. On p. 405 is the following statement: "The Shinarump constitutes the horizon of silicified trunks and there is no part of it in which fossil wood does not occur in great abundance."

[3] See C. D. Walcott, "The Permian and Other Paleozoic Groups of the Kanab Valley, Arizona," *Am. Jour. Sci.*, 3d Ser., XX (1880), 221.

[4] Interpretation by Eliot Blackwelder (personal communication).

sediments giving place to non-clastic in the same direction; (4) fluviatile deposition most important; (5) all deposits in relatively shallow water, or subaerial; (6) oscillating marine and non-marine conditions at edge, non-marine in most of region of deposition; (7) moderate aridity long continued in some parts of the region of deposition, alternating with less arid conditions in other parts.

These conditions coincide to a remarkable degree with those inferred from the study of modern red sediments.

RELATION OF DIASTROPHISM TO RED BEDS SEDIMENTATION

It may well be asked at this juncture why it is that earlier Carboniferous clastics underlying the Red Beds of Oklahoma and other states are not similarly colored. The difference in color, since this has been shown to be a feature dating from the time of sedimentation,[1] must be due to differences of some sort in the geographic conditions of the times when the successive series were deposited. One of these differences is the emergence of the plains of deposition. Another may be found in the fact that some, at least, of the highlands from which the Red Beds derived their materials were not in existence in the earlier part of the Paleozoic era. The Arbuckle-Wichita uplift probably dates from the later part of the Pennsylvanian period; and there may have been mountain-building in Colorado at the same time, as the stratigraphic relationships of the scattered Paleozoic sediments in that state seem to indicate. Dr. Blackwelder[2] calls attention in this connection to the fact that the general trend of the Arbuckle-Wichita folding is directly in line with the suspected areas in Colorado. Local climatic changes influencing the type of sedimentation may have been brought about by these changes in topography. The general continental expansion of North America from Pennsylvanian to Jurassic times leads one to expect extreme types of continental climate, including aridity, the localization of which would depend largely on the configuration of the continent.

The deposition of red sediments derived from ferruginous soils means either the development of red soils and the transportation of the material thereof without hydration, or the development of

[1] See discussion of this point, pp. 162–67, this volume.

[2] Personal communication.

limonitic ferruginous soils and the dehydration thereof during transportation. The development of ferruginous soils is the chief prerequisite to the deposition of Red Beds of the western type.

The areas from which the Red Beds derived their materials certainly included uplands, and in part at least they are known to have been possessed of fairly rugged relief; they were therefore in all probability the sites of more abundant rain than fell upon the plains or delta flats upon which the Red Beds were in large part deposited. The combination of well-watered highlands with less humid or semi-arid lowlands furnishes the conditions for the development of red soils, and at the same time provides for the transportation and deposition of the sediments derived from them without extensive hydration or reduction of the ferric oxide constituent during the transfer.

An unusually extensive development of red soils during the time of deposition of the Red Beds might have been due, in some part at least, to the higher proportion of oxygen inferred by Chamberlin and Salisbury[1] to have existed in the atmosphere at this time.

SUMMARY

The several steps which have been followed in the interpretation of the color of the Red Beds, and the results obtained, may be summarized as follows:

1. The ferruginous matter which gives the Red Beds their color has been present in the series in very nearly its present distribution and arrangement since the time of sedimentation.

2. This material has suffered no extensive change of ferrous to ferric iron, or vice versa, since the time of sedimentation; the proportion and present distribution of these compounds in the series were influenced most largely by the original distribution of organic matter.

3. Changes in the degree of hydration of the ferric oxide in the Red Beds since sedimentation probably have not been of great importance; and hydration probably has been quite as active as the reverse process during this time.

[1] T. C. Chamberlin and R. D. Salisbury, *Geology* (New York: Henry Holt & Co., 1909), II, 665.

4. The ferruginous matter of the Red Beds was transported and deposited almost, if not quite, wholly as a mechanical sediment, both independently and as a coating upon grains of other material.

5. The types of sediments probably most important in the Red Beds group are stream deposits, submarine fluviatile deposits, and playa deposits, all predominantly of red color, and all deriving at least the greater part of their ferric oxide from ferruginous residual soils. Of these types the first is by all odds the most important.

6. The study of characteristics of the Red Beds other than color bears out the conclusion stated in No. 5.

7. The inauguration and cessation of Red Beds sedimentation probably were connected closely with climatic and topographic changes involved in the orogenic history of the continent.

The colors which distinguish Red Beds from other series are due to a combination of lithologic, topographic, and climatic factors in the regions of denudation and in those of deposition, which have not been reproduced over so great an area in more recent times.

It is apparent that, in accordance with Barrell's view,[1] "red color in sediments is not in itself an indication of aridity"; for the material of red ferruginous soils may be transported and deposited in regions of high rainfall, or even under the sea, without change of color; and red soils themselves develop in regions of heavy rainfall. But since the dehydration of the limonitic material of non-red ferruginous soils, as well as the continuance of the relatively anhydrous condition of the hematitic material of red soils, is favored by aridity in the regions of transportation and deposition, therefore red sediments should form a larger part of the sediments of arid than of humid regions.

[1] Joseph Barrell, "Upper Devonian Delta of the Appalachian Geosyncline," *Am. Jour. Sci.*, 4th Ser., XXXVI (1913), 437.

THE ACADIAN TRIASSIC

SIDNEY POWERS
Troy, New York

PART III

STRUCTURE OF THE ACADIAN TRIASSIC

The Newark rocks in the Acadian area exhibit a monoclinal structure, with a prevailing northwesterly dip, interrupted by broad, low folds. The monocline is broken by numerous faults with a small displacement and by occasional faults with a displacement of hundreds of feet. The other areas of Newark rocks have undergone deformation of a similar nature, but the direction of the monoclinal tilting differs in the various areas. In the case of the Connecticut Valley, the Pomperaug Valley (Connecticut), the Deep River (North Carolina), and the Wadesborough (North Carolina) areas, the dip is southeast, where as in all the other areas it is northwest.

The two structural features, the folds and faults, will be treated separately and finally some attention will be given to the theories of origin of this structure.

FOLDS

The most important and the most conspicuous fold in the Acadian area is that shown by the hook in North Mountain which incloses Scots Bay. The point of the hook forms Cape Split, and the back of the hook, Cape Blomidon. This syncline pitches down on the north side and is cut off on the north by a fault shown in cross-section DD, Fig. 28. The syncline is shown principally in the North Mountain basalt which dips toward Scots Bay on all sides of the Bay at angles of about 5°. Under the basalt flows the Blomidon shale is seen following the erosional escarpment, on the south side of North Mountain, around to Cape Blomidon, near which point it disappears under the waters of Minas Basin, as

shown in Fig. 27. Above the North Mountain basalt comes the Scots Bay formation, the youngest formation in the Newark group of the Acadian area. The Scots Bay formation is exposed on the south side of the Bay, as shown in Fig. 27.

The eastern extremity of Minas Basin, east of Economy Point (the area shown in Fig. 23), also forms a syncline which has been disturbed by faulting at various points. The beds of red sandstone on either side of Cobequid Bay dip toward the bay at angles of about 3°–5° except where they have been tilted by faulting. This gentle dip must simulate that of the strata when they were first deposited in the slowly subsiding geosyncline.

A syncline, which is well shown in a shore section, is found at Quaco, between West Quaco and Melvin's Beach, on the north side of the Bay of Fundy (see cross-section BB, Fig. 7). The sediments of the Quaco section are readily identified by the Quaco conglomerate in the center. This conglomerate is exposed on the shore near Vaughan Creek with a dip of 30° to the north and again a mile inland (northwest) with a corresponding dip to the south. The syncline is cut off obliquely on the north by a fault in such a way that the axis of the syncline is shown in the shore section near Melvin's Beach, but the Quaco conglomerate of the northern limb does not reappear.

At Split Rock a low anticline is shown, at Martin Head a syncline, and at Waterside an anticline and the adjoining syncline. In each of these cases the folds are cut off by faults. The folds are at a low angle with broad arches or troughs.

Cape d'Or shows a small syncline in the basalt flows where the basalt ridge turns, from its east-west course, to make the Cape on the south. Horseshoe Cove has been formed at the axis of the syncline. The basalt is also faulted as is shown in Fig. 12.

Everywhere in the sea-cliff exposures there are minor flexures in the Acadian Triassic, both in the sediments and in the igneous rocks. In Fig. 19, an example of the folds in the sediments west of Five Islands is given. In the North Mountain basalt, gentle folds are shown at Scots Bay, where the Scots Bay formation is preserved in synclines (Fig. 29), and at Digby Gut, where a long syncline is shown at Victoria Beach.

FAULTS

The disturbance at the close of the Newark sedimentation threw the rocks of this group into fault-blocks with a monoclinal tilting toward the northwest. With such a structure, the major faults would tend to assume a northeast-southwest trend, and some of the more important faults should bound the formation on the north and northwest.

The faults at the margin of the Triassic area are confined to the northern and western sides. Thus the basalts of Grand Manan are faulted down on the west side, while the pre-Triassic rocks on the east side of the island are probably tilted up. The older formations against which the basalts were downthrown have since been eroded away, because they were less resistant than the basalts, and Grand Manan Channel has been formed in them.

The northern and northwestern sides of the Triassic areas at Split Rock, Quaco, Martin Head, and Waterside are all dropped down as fault-blocks against older rocks. At Martin Head the pre-Cambrian rocks form Martin Head itself, which is south of the exposure of the Triassic sediments. This exposure of older strata may be explained either as a horst or as the basement upon which the southern limb of the Triassic syncline rests. The latter view is favored, making the Triassic and the exposure of pre-Cambrian part of one fault-block, with a fault south of the pre-Cambrian. There also appears to be a minor fault in the axis of the Martin Head syncline.

The fault of greatest displacement in the Fundy region is the Cobequid fault (shown on the general map of the region), which stretches from West Advocate, north of Cape d'Or, to a point northeast of Truro, a distance of 90 miles. On the north side of the fault is the Cobequid group of sedimentary and igneous rocks which composes the Cobequid Mountains. On the south side of the fault are Triassic sandstones at West Advocate and Advocate Harbour, and Pennsylvanian rocks east of Advocate Harbour. The displacement of this fault is probably 2,000–3,000 feet.

South of the Cobequid fault is another east-west fault which bounds the Triassic on the north from Cape Sharp to the Chiganois River (northeast of Truro). The displacement of this fault appears

to be greatest on the west, with a downthrow of 1,500 feet or less. Parallel to this fault is another at Clarke Head which has brought the Triassic down on the north against older rocks on the south, forming a small graben shown in Fig. 17. All the rocks at Clarke Head are intensely faulted.

The remnants of North Mountain basalt at Cape Sharp and at Partridge Island appear to be faulted off on the south side. The throw of this fault is uncertain in direction, but it may be a continuation of the southernmost fault at Clarke Head.

The exposure of North Mountain basalt at Cape d'Or exhibits several faults in a north-south direction, as shown in Fig. 12. The end of Cape d'Or is probably on an east-west fault line. This same fault may extend eastward.

The Five Islands region exhibits complex block-tilting with blocks of relatively small size. Besides the fault bounding the Triassic on the north, and the Cobequid fault farther north, an east-west fault is shown at Gerrish Mountain (Figs. 20, 22). The Five Islands are each separated by faults and are each tilted in different directions. These faults on the north become lost in a greatly slickensided region shown in detail in Fig. 21. The slickensided surfaces are usually vertical and have a north-south direction. The major movement appears to have been in a horizontal plane, but the stratification shows that there also has been vertical movement. Many other north-south faults are shown along the shore from Clarke Head to Five Islands, and a typical section is shown in Fig. 19.

Near Lower Economy a strike (east-west) fault brings the Triassic down into contact with a mass of Pennsylvanian strata on the north on which the Triassic rests unconformably.

The hook of North Mountain, at Cape Split, is cut off by a northeast-southwest fault which gradually cuts across this limb of the Scots Bay syncline.

North Mountain is composed of basalt flows tilted to the northwest so that an erosion escarpment is produced on the south side of the mountain and a gentle dip-slope on the north side. The sea-cliffs on the north side are never very high for this reason. With a continuation of the dip-slope, the erosion top of the flows

appears to extend under the Bay of Fundy. The coast charts do not show any pronounced submarine ridges parallel to North Mountain, such as some authors have referred to, and therefore there is a lack of evidence of any major fault parallel to North Mountain. Moreover, no geological structure under the Bay of Fundy appears to be deducible from the submarine topography.

Cross-faults in North Mountain are readily shown by offsets in the ridge of basalt flows because the flows are dipping at a low angle northwest. The offsets are at Digby Gut, Bay View, Gulliver's Cove, Petit Passage, Grand Passage, and southwest of Brier Island. The line of these faults is north-south. The displacement of the flows by these faults, with the exception of the first and last faults, is to the north on the west side of the fault. These offsets are shown on the accompanying general map of the region. The offset at Digby Gut is shown on Fig. 30, and that southwest of Brier Island is shown by the position of a short submarine ridge on the coast chart.

As shown by Daly[1] and by Haycock,[2] these fault lines across North Mountain, and also the depressions at Parker Cove and Sandy Cove were occupied by rivers at the time that the Summit peneplain was being developed over the region. When the peneplain was uplifted the rivers became rejuvenated and persisted in their courses until the present valleys were cut. Headward erosion up the valley which is now St. Mary's Bay diverted the streams flowing across the basalt south of Bay View, and the more rapid erosion in Digby Gut caused the abandonment of the Bay View and Parker Cove valleys.

THEORIES OF ORIGIN

The faults which traverse the rocks of the Newark group are of deep-seated origin, extending into the older formations. The character of the underlying formations varies with the different areas. Thus the Acadian Triassic is underlain in part by Carboniferous folded sediments, in part by Silurian and Devonian slates and

[1] R. A. Daly, "The Physiography of Acadia," *Bull. Mus. Comp. Zoöl., Harvard College*, XXXVIII (1901), 92.

[2] E. Haycock, "Records of Post-Triassic Changes in Kings County, Nova Scotia," *Trans. N.S. Inst. Sci.*, X (1900), 297.

Devonian granite, and in part by pre-Cambrian slates (the Meguma series) and other metamorphic rocks (the pre-Cambrian complex of New Brunswick). The Connecticut Valley area is underlain by gneisses and schists, the New Jersey area by gneisses and some Paleozoic sediments, and the Richmond area by gneisses and granites. A theory which accounts for the structure of the Newark beds must therefore suit the various basement rocks.

Davis,[1] in studying the Connecticut area, reached the conclusion that the origin of the monoclinal fault structure was the slipping of blocks of the underlying crystalline rocks on each other along cleavage planes. As pointed out above, although the Connecticut area is underlain by gneisses and schists, the other Newark areas are not. Suitable cleavage planes would therefore not be expected in the other areas.

In the Minas Basin region, the crystalline rocks are several thousand feet below the base of the Triassic. Furthermore, the planes of slipping in these crystallines are parallel to the main structural lines of the formation. These lines run at an angle to the axis of Minas Basin, as is seen in the nearest exposures of the crystallines (the Meguma, or Gold-bearing series). The theory proposed by Professor Davis does not seem, therefore, to apply to the Acadian area.

Hobbs[2] considers that Professor Davis' theory does not suit the facts in the Connecticut Valley or in the Pomperaug area. For the latter area, Hobbs proposes another theory to account for the peculiar system of quadrangular block-faults. As this detailed faulting is not typical of all the Newark areas, the theory is of limited application.

Professor Barrell[3] has recently ascribed the origin of the Connecticut Valley Triassic area to the gradual development of a fault on the east side of the geosyncline, contemporaneously with the

[1] W. M. Davis, "The Structure of the Triassic Formation of the Connecticut Valley," *U.S. Geol. Surv., 7th Ann. Rept.*, 1888, pp. 486–89.

[2] W. H. Hobbs, "The Newark System in the Pomperaug Valley, Connecticut," *U.S. Geol. Surv., 21st Ann. Rept.*, Part 3 (1901), pp. 122–33.

[3] J. Barrell, "Central Connecticut in the Geologic Past," *Proc. Wyo. (Penn.) Hist. and Geol. Soc.*, XII (1912).

filling of the basin with sediments. This fault is supposed to have been initiated after sedimentation commenced, and to have increased in displacement with the accumulation of the sediments.

In the Acadian area a corresponding fault is found on the north and west, but there is no evidence that this fault developed until sedimentation ceased. No completely satisfactory theory to account for the structure has yet been presented.

IGNEOUS ROCKS

DISTRIBUTION

A description of the igneous rocks in each locality has been given in the description of the general stratigraphy of the region, and therefore merely a summary is attempted here. The flows at Cape d'Or have been especially studied, and will be considered in a separate paper by Professor Alfred C. Lane and the writer.

All of the igneous rocks associated with the Acadian Triassic are of a basaltic composition. From the form of occurrence, they are grouped into dikes and flows. According to the time of formation, they are classified as the Five Islands volcanics and the North Mountain basalts. Dikes are so rarely exposed that it is necessary to consider the rocks from the point of age, rather than form.

In Nova Scotia, outside of the Triassic area there are some diabases and basalts which are probably of Triassic age. At Cheverie, near the Avon River, there is a sill of diabase intruding Pennsylvanian strata.[1] Again, in Guysborough County, near Guysborough, Fletcher has mapped on the sheets of the Geological Survey of Canada masses of diabase cutting the Union-Riversdale series. The nature of these masses is described by Fletcher[2] as partly amygdaloidal, partly dioritic.

Dikes of Triassic age occur in a number of places between Nova Scotia and the Connecticut Valley. The large majority of them are of diabase composition.

[1] Verbal communication from Mr. W. A. Bell, of the Geological Survey of Canada.

[2] H. Fletcher, *Geol. Surv. of Canada, Annual Report*, 1886, pp. 101–3 P; also *Geol. Surv. Canada, Maps, Nova Scotia*, Nos. 30, 31, 35, 36.

FIVE ISLANDS VOLCANICS

Under the heading Five Islands volcanics are included the tuffs, agglomerates, and basalt flows in the vicinity of Swan Creek and the Five Islands. The thickness of the volcanics is estimated as at least 350–400 feet. One associated dike is exposed at Gerrish Mountain.

The Gerrish Mountain diabase dike is almost vertical and about 20 feet or more in thickness. The diabase shows marked columnar jointing, the columns being rather short and largely horizontal or dipping at a low angle to the horizontal. The dike is connected with the basalt flow which caps the sandstones of Gerrish Mountain, and it has evidently furnished the material for this flow and perhaps for a large part of the other igneous rocks for the vicinity.

The basalt flows associated with the Five Islands volcanics are found at Gerrish Mountain, on four of the Five Islands, on Two Islands, and at Portapique Mountain (east of Gerrish Mountain). It is noteworthy that the relation of these flows to the agglomerates is unknown, and that there is no proof that they are not connected with the North Mountain basalt instead of with the Five Islands volcanics. The structure of these flows is in large part columnar, and the base and the top of each individual flow is marked by amygdaloid. The basalts are the usual fine-grained, dark-gray, heavy rocks composed of augite and plagioclase with accessory amounts of magnetite and occasionally olivine. A more detailed petrographical description will be given below for the North Mountain basalt, which will apply equally well to these flows.

Only one flow is exposed in Gerrish Mountain. This has a thickness of over 75 feet. Three flows are exposed on the north side of Moose Island, the upper one being agglomeratic. A portion of a single flow is exposed on Diamond Island and on Long Island. Two flows are seen on Pinnacle Island. The northern of the Two Islands consists of three flows, the southern of probably only one.

The base of the series of flows is exposed on the eastern side of Moose Island and on Gerrish Mountain. Under the amygdaloid which marks the base of the flow is a layer of green ash 2–3 feet in

thickness. A similar ash-bed is exposed west of Swan Creek under the agglomerate flow mentioned below. The thickness of the flows on Gerrish Mountain may be considerable, as the basalt covers a large area.

The agglomerate beds, with associated tuffs, are exposed from Greenhill eastward to Five Islands, in disconnected areas. The relation of these remnants of flows and volcanic ejectamenta to the sandstones is a problem only partly solved because of the faulted contacts, with possibly minor thrust-faults, and the landslides which are especially abundant in the tuff. The tuff underlies the agglomerate in most cases. The thickness of the tuff varies from a few feet to 50 feet, and that of the agglomerate flows from 20 to 150 feet or more. Exposures show that the agglomerate is overlain by red sandstone, and is therefore older than the North Mountain basalt.

The agglomerates consist of a mass of angular fragments of basalt and amygdaloid in a dark-green matrix of a basaltic composition. The exact character of the matrix is difficult to determine because it is everywhere so badly weathered that a solid specimen could not be procured. The field evidence, however, indicates that this matrix is in part tuffaceous and in part a normal basalt. At the sides of some of the masses of agglomerate are blocks of angular basalt and amygdaloid imbedded in a red sandstone matrix, showing that the breccia was either blown out into the area where sandstone was being deposited, or washed out from a bed of tuff and breccia. The cross-cutting contacts at one side of the masses of agglomerate in two instances give them the appearance of intrusive bodies rather than of flows. If the agglomerates are intrusive, rather than extrusive, they probably fill volcanic necks.

NORTH MOUNTAIN BASALT

Under the term North Mountain basalt, used in a generic sense, are included the basalt flows of Grand Manan, Isle Haute, Cape d'Or, Cape Sharp, Partridge Island, and North Mountain. The series of flows at these localities are correlated either for structural reasons or because they are underlain by shale correlated with the Blomidon shale.

In each locality there are several flows, indicating successive extrusions within such a short time of each other that no sediments were deposited between the flows. It is impossible to state whether any single flow originally covered the geographical area over which the remaining exposures indicate that the formation once extended. The Palisade diabase formes one sill 100 miles long on the outcroping edge, while North Mountain is 120 miles long. In the former case the igneous material was intruded at some distance below the surface and had to push up this great weight of rock, which, however, acted as a blanket over the feeder. In the latter case the igneous material was extruded at the surface, with no roof to sustain, but the feeders were constantly subjected to the great heat loss by radiation at the surface, which would tend to freeze them up.

Dikes associated with the North Mountain basalt are rare. Several were reported on Grand Manan by Bailey,[1] but they were not observed by the writer. The largest of these is 50 feet wide, and occurs at Flag Cove, near Swallow-Tail Light.

Other narrow dikes occur on the south side of Scots Bay, just east of the Scots Bay formation exposures. These dikes cut the basalt within 25 feet of the top of the upper flow. From the other exposures of this flow it is judged to be at least 100 feet thick, and, if so, it is quite evident that the dikes cut the upper flow and are not the feeders. With the dikes are many fissures filled with vein material which is seen under the microscope to consist largely of silica stained red with hematite. The width of both the veins and the dikes varies from one to ten inches, and in the field they look very much alike.

In thin-section the dikes are seen to consist of a very fine-grained diabase, greatly altered and stained with limonite. The rock is similar to that of the flows near the center, but shows some glass.

From the field evidence of the dikes and veins side by side in the upper part of this thick flow, and from the microscopic evidence, it is concluded that the dikes were formed from the basalt of the upper flow after the crust of the flow had solidified and while the

[1] L. W. Bailey, *Geol. Surv. Canada, Report of Progress*, 1870, pp. 216–21.

center of the flow was still liquid. The crust appears to have become fissured, with some of the fissures reaching down to the still molten rock, and other of the fissures having no great depth and therefore being filled with quartz from above at a later stage.

The structure of the flows is similar to that of all basalt flows. The individual sheets are clearly distinguished by a relatively thin amygdaloidal base and a relatively thick amygdaloidal top. Flows composed entirely of amygdaloid were observed only at Cape d'Or. The basalt is closely jointed and columnar joining is frequently developed. The angle at which the columns and planes between the sets of columns stand with respect to the vertical and horizontal, respectively, indicates the dip of the flow. Faulting in the sheets is frequently obscured by jointing.

In North Mountain, from Cape Blomidon to Cape Split, and along the Victoria Beach shore of Digby Gut, the thickness of the flows may be estimated. A partial section is exposed at Sandy Cove and at Freeport, on Long Island, and at Tiverton, on Brier Island. In most of the sections the lowest flow is the thickest, and at the top of the series are several thin flows.

The section from Cape Blomidon to Cape Split shows two and probably three flows, each with an estimated thickness of 150–300 feet. The top of the upper flow is exposed around the edge of Scots Bay. It exhibits the small folds into which all the basalt flows have been thrown. No other sections of the North Mountain basalt are exposed until Digby Gut is reached, because the sea-cliffs are low and expose only the upper flow or flows.

At Victoria Beach the best section is found. There is some doubt if the lower flow, as here estimated, is not composed of two separate flows, but the microscopic examination of slides made from the first exposures above and below the blank in the section indicates a coarseness of grain which characterizes the center of a thick flow. Erosion has probably removed several flows from the top of the section. The section consists of:

Top.	Six flows 2–45 feet in thickness	160± feet
Base.	Main flow	600+ "

The upper flows of the Victoria Beach section are absent from the exposures at the end of Digby Neck. They have either been

removed by erosion or were never deposited there. The thicknesses of the portions of the flows remaining between the waters of St. Mary's Bay on one side and the Bay of Fundy on the other are estimated as:

	Sandy Cove	Tiverton
Upper flow	300± feet	150+ feet
Lower flow	150± "	75+ "

On Grand Manan the section is quite similar to those given above. The number of thin flows on the top of the series was not counted accurately. The section is:

Top.	Ten(?) thin flows averaging 10–15 feet in thickness	100 feet
	Second flow	250 "
Base.	First flow	450 "

The number of flows exposed on Isle Haute is unknown. The section at Cape d'Or consists of 5 flows, of which the lower one (556 feet) is the thicker. At Cape Sharp and at Partridge Island two flows appear to be shown.

Only one petrographic description of the basalt of North Mountain has been published.[1] On account of the similarity of the basalts associated with the Newark group little attention has been paid to those of the Acadian area.

The basalt is a dark-gray or dark-greenish fine-grained rock composed of plagioclase feldspar and augite with accessory amounts of magnetite, olivine, and glass. The feldspar is a labradorite, varying slightly in composition. The texture of the rock is ophitic, laths of feldspar inclosing augites, or masses of augite inclosing small feldspar laths. Chlorite, magnetite, limonite, hematite, and serpentine are present as alteration products.

The proportion of glass to crystalline matter, of labradorite to augite, and the presence of olivine each depend on the proximity of the section to the top or bottom of the flow. The top of the flow is always quickly chilled in contact with the atmosphere, and solidifies with a large amount of glass and a large number of gas cavities. These cavities later become filled with quartz, calcite,

[1] V. F. Marsters, "Triassic Traps of Nova Scotia," *Am. Geol.*, V (1890), 140–43.

or some other mineral to form amygdules. At the base of the flow, rapid chilling also takes place; less glass is developed, but well-crystallized magnetite is found. Alteration, however, soon commences in the base of the flow because of the reaction of heated waters on the basalt.

The glass, characteristic of the top and the bottom of a flow, frequently contains most of the feldspar in laths already formed, showing that the feldspar had commenced to crystallize before the augite. In other cases the glass is accompanied by both augite and feldspar. The glass always has a cloudy appearance.

Gravitative adjustment takes place in all flows which are sufficiently thick, and which remain hot sufficiently long for a movement of the crystallizing magma to take place without being recorded in flow structure. As in the case of the Palisade sill, olivine tends to form near the base of the flow and in the quickly chilled top.

Gravitative differentiation is also shown in the relations of the labradorite to augite. The augite settles toward the base of a flow as in the case of a sill, and the feldspar rises.

The chemistry of the Cape d'Or flows will be treated in a separate paper, but it may be stated here that those basalts show a normal composition, averaging about 52.5 per cent silicia, 14.3 per cent alumina, 9.8 per cent lime, 2.5 per cent soda, and 1 per cent potash.

Rosiwal measurements on thin sections from the center of a 556-foot flow show a mineralogical composition of 40 per cent plagioclase feldspar, 56.5 per cent augite, and 3.5 per cent iron ores.

All the basalts show more or less alteration and disintegration except where rapid marine erosion exposes fresh rock. The amygdaloid, even where fresh, is always altered. In the drill-cores at Cape d'Or, the same character of alteration was shown in each amygdaloidal layer. A certain amount of hematite, with limonite, is developed, giving these rocks a reddish color.

Veins are very common in the dense basalts as well as in the amygdaloids. The veins are formed of jasper or quartz, with either reddish (hematite) or greenish (malachite or chlorite) walls.

ORIGIN

The basalt unconformity of the Acadian Triassic always shows upturned and beveled rocks overlain by Newark sandstones or conglomerates with bedding parallel to the underlying erosion surface. This fact indicates that the Newark sediments were deposited on a peneplain, as has been found the case in the Connecticut[1] and Richmond[2] areas.

On this peneplain, an orographic basin was formed, and into the geosynclinal area sediments were brought from all sides. An equilibrium between the rate of sedimentation and of subsidence of the geosyncline appears to have been reached when the Blomidon shales were deposited at the top of the Annapolis formation.

The Wolfville sandstone at the base of the Acadian Newark shows red sandstones and occasional conglomerates and shales, in general evenly bedded. The pebbles in the conglomerates are stream-worn, but are frequently subangular. The character of the Quaco conglomerate has been sufficiently treated. The Wolfville sandstone indicates stream transportation, with deposition in flood-plains, and perhaps in past in broad alluvial fans.

The Blomidon shales are generally evenly bedded, but show occasional ripple or current marks, and rarely mud cracks. The presence of *Estheria* indicates temporary bodies of water. Flood-plains of mature rivers would furnish the necessary conditions for the deposition of shales, with cut-off lakes in which the crustaceans could live.

The red color of the Annapolis formation evidences long oxidation of the iron during transportation and deposition.[3] The white or gray color indicates a lack of hematite, and the green color is caused by the presence of chlorite.

The climate during the deposition of the Annapolis formation was apparently hot and dry, with occasional floods. The presence of calcite in nearly all the sediments, and the scarcity of arkose,

[1] W. M. Davis, *U.S. Geol. Surv., 18th Ann. Rept.*, 1898, p. 20.

[2] N. S. Shaler and J. B. Woodworth, *U.S. Geol. Surv., 19th Ann. Rept.*, 1899, p. 408.

[3] J. Barrell, "Relation between Climatic and Terrestrial Deposits," *Jour. Geol.*, XVI (1908), 159–90, 255–95, 363–84.

and of plant and animal remains, all favor long oxidation of the sediments in a dry tropical climate.

The Scots Bay formation was deposited in part, at least, in a lake, because fish remains occur in the strata. This lake came into existence soon after the extrusion of the North Mountain basal flows, as is indicated by the lack of erosion in the upper amygdaloid.

The Five Islands volcanics are interpreted as representing a phase of igneous activity slightly earlier than that in which the North Mountain basalt flows were extruded. The volcanics may have come from central vents as well as from fissure eruptions.

The North Mountain basalt must have come from fissure eruptions, and spread out over a large portion of the Triassic geosyncline, as is indicated by the widely separated areas at North Mountain and at Grand Manan. The geographical extent of any individual flow is impossible to determine, but it appears that the earliest flow, or series of flows, was the thickest.

The physiographic conditions accompanying the formation of the Five Islands volcanics and the North Mountain basalts are poorly shown. The base of the North Mountain basalt is exposed only on Grand Manan, and there it is greatly weathered. No evidence of contemporaneous lakes over which the lava flowed has been found.

THE LOMBARD OVERTHRUST AND RELATED GEOLOGICAL FEATURES

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SUMMARY

TOPOGRAPHIC AND STRUCTURAL FEATURES

The region involved in this discussion lies near the head of the Missouri River in Montana. The chief topographic features are hilly dependencies of the Little Belt Mountains.

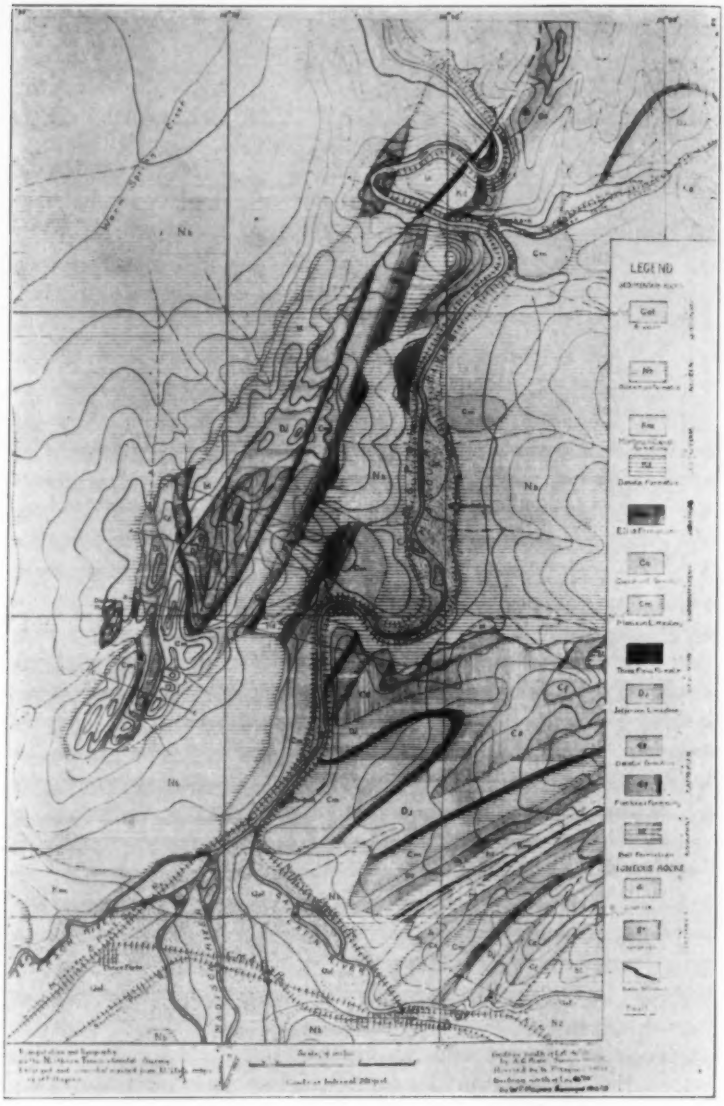

FIG. 1.—Geological map of the region about Three Forks, Montana

The principal structural features are shown on the map (Fig. 1) and in the structure sections (Fig. 2). The dynamic features consist of folds and faults.

FOLDS

There is no indication that any marked deformation took place in this region during the Paleozoic and Mesozoic eras. At the close of the Cretaceous period, probably, the great series of sediments which had been accumulating began to be deformed. In this region they were compressed into a series of closed folds with a general northeast-southwest trend. These folds are usually overturned to the southeast and pitch to the southwest. Two of these folds were named by Dr. Peale[1] the Horsehoe anticline and the Cottonwood isocline, both situated north of Logan, Montana.

East of Lombard, in the vicinity of Crane Station, there is a northward-pitching anticline. In the long ridge west of the Missouri River there is an elongate domal structure (Fig. 3) the western side of which is interrupted by a normal fault and obscured by an extensive overthrust. The southern part of this elongate dome is overturned to the east and pitches steeply to the south (Fig. 1; Fig. 2, section D-D; and Fig. 4).

FAULTS

The Lombard overthrust.—The most important feature of the structural geology of the region is an extensive overthrust fault which has its southern end in the ridge north of Three Forks, and extends a distance of at least 13 miles along the ridge to the northern border of the map. The writer proposes the name "Lombard overthrust" for this feature, because it is well exposed in the canyon of the Missouri River near Lombard. Here the fault plane dips about 40° to the west. This fault has brought strata of the Belt Series over strata of Cretaceous age in the north, near Lombard, and has brought the upper member of the Cambrian into contact with the Carboniferous Madison limestone in the southern end of the ridge (Figs. 2 and 5). The maximum displacement on the fault plane near Lombard cannot be very closely estimated,

[1] A. C. Peale, *Bull. U.S. Geol. Survey, No. 110*, 1893.

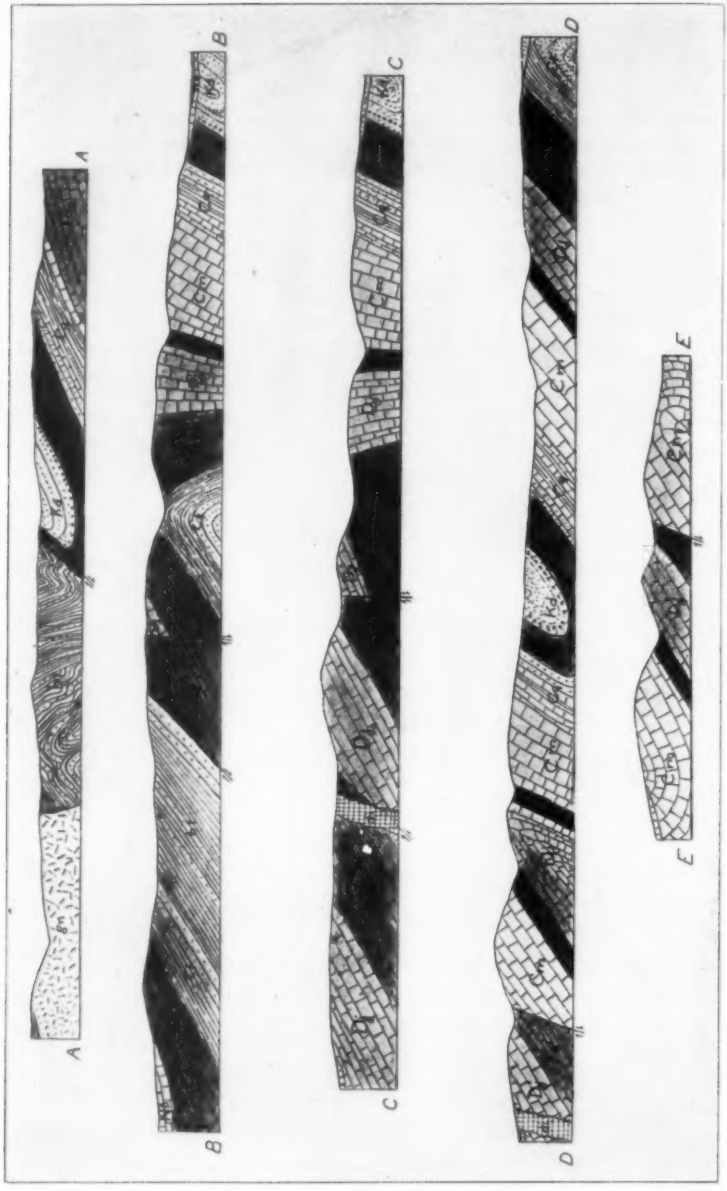

FIG. 2.—Geological sections

but it is approximately two miles, and strata which are stratigraphically about 6,800 feet apart are here in contact.

The age of the Lombard overthrust cannot be definitely determined, but it is certainly younger than the Cretaceous strata exposed near Lombard, and probably older than the Lower Oligocene deposits which occur near the southern end of the ridge and are apparently undisturbed. It may therefore be assigned with some uncertainty to very late Cretaceous or early Tertiary time.

A normal fault.—The only normal fault observed in this region appears in the highest part of the ridge north of Three Forks and west of the Missouri River. This fault cuts across the western limb of the elongate dome already noted, and has caused a repetition of the upper part of the Gallatin formation and the base of the Jefferson limestone (see Fig. 2, section C-C). This fault has a length of about two miles and a diminishing throw to the south. It could not be traced to its intersection with the overthrust fault, but the displacement apparently dies out in that direction also.

The age of the normal faulting is considered to be the same as that seen farther south in the Three Forks quadrangle, which is dated as probably Pliocene.

STRATIGRAPHIC GEOLOGY

PRE-CAMBRIAN

The oldest rocks exposed in this region are a series of somewhat altered sediments which occur below the base of the Cambrian, and are considered to be part of the Belt Series, which are typically exposed in the Little Belt Mountain region to the north and northeast. The exposures of the Belt formation occur along the Gallatin River east and northeast of Logan, and also north of Three Forks, in a widening strip which trends northeastward and crosses the Missouri River at the double horseshoe bend west of Lombard (Fig. 1).

The exposures north of the Gallatin River are of rather coarse micaceous sandstones and shales with thinly bedded siliceous limestones. They are not divisible on the basis of lithological characters into the various formations which characterize the Belt Series at the type localities.

FIG. 2.—Geological sections

The extensive exposure of the Belt Series north of Three Forks, which, so far as the writer was able to ascertain, has not been described before, consists of two fairly distinct formations which are considered to be equivalent to the Spokane and Empire formations of the Belt Series.

Spokane formation.—In the vicinity of the double horseshoe bend of the Missouri River there is a fine section through the

FIG. 3.—Domal structure in ridge west of the Missouri River

Spokane formation. The formation at this place consists of a thick series of well-stratified red and green slates with frequent layers of ripple-marked and mud-cracked sandstone. The finer beds are mostly very hard and siliceous and may be called argillites or even metargillites. At several places in the section distinct folds are visible, and also some faults. The minimum thickness of the formation in this section is 1,650 feet, but the average thickness is probably considerably greater than these figures.

Empire shale.—This formation, which overlies the Spokane formation, is exposed in a long strip west of the Missouri River,

extending from near the southern border of the Fort Logan Quadrangle near latitude 46° to the double horseshoe bend. It consists of evenly bedded, pale greenish shales with a few bands of quartzite. The quartzite occurs in beds from 1 to 25 feet thick. The formation is in apparent conformity with the overlying Cambrian

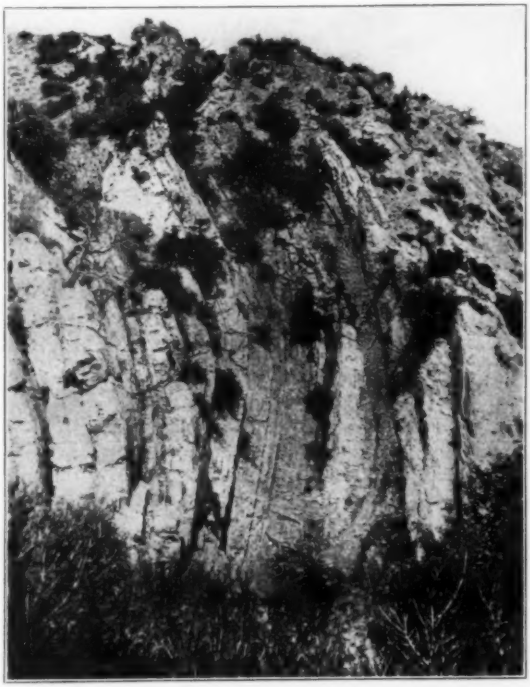

FIG. 4.—Folded Madison limestone near southern end of ridge, north of Three Forks.

quartzite near the southern end of the exposure, but inasmuch as the contact was traced for only a short distance an unconformity with very slight angular discordance may have been overlooked. Although the complete section of the Empire shale was not seen, it is probable that 800 feet is a conservative estimate for the thickness of the formation in this area.

There is still much disagreement among the various geologists who have worked in the parts of the Cordillera where the Belt Series is exposed, in regard to the age of the series and the correlation of the different formations in it. The writer is disposed to agree with the correlation in a recent report on the Philipsburg quadrangle in Montana,[1] in which strong evidence is shown for a rather long erosion period between the Belt Series and the overlying Cambrian quartzite. The two formations identified by the writer as the Empire and Spokane formations are therefore considered to be of Pre-Cambrian, Algonkian, or Proterozoic age.

PALEOZOIC

The Paleozoic formations recognized by the writer in this region are for the most part continuous with those described by Dr. Peale in his report on the "Paleozoic Section in the Vicinity of Three Forks, Montana,"[2] and later in the Three Forks Atlas Folio.[3] His descriptions of the formations are very good and apply equally well to the exposures in the region to the north, on the Fort Logan Sheet. There are some additional facts concerning the thicknesses and ages of the formations and a few changes in the nomenclature which will be discussed under the following headings:

Cambrian.—A comparison of sections made by different geologists in the neighboring quadrangles shows that the seven lithologic divisions noted by Dr. Peale in the Three Forks quadrangle are persistent throughout southwestern Montana and the neighboring part of Wyoming. It seems advisable to have but one name for each of these divisions, and since locality names are preferable to descriptive names the writer suggests that the nomenclature used by Dr. Weed[4] in the Little Belt Mountains Folio be adopted for the Cambrian throughout the whole region where these seven lithologic divisions are recognized.

For purposes of mapping it seems best to keep the broader divisions used by Dr. Peale, the two lower members forming the Flathead formation and the upper five the Gallatin formation.

[1] *Prof. Paper 78. U.S. Geol. Survey.* [2] *Bull. U.S. Geol. Survey, No. 110.*

[3] Atlas Folio, *U. S. Geol. Survey, No. 24.*

[4] Atlas Folio, *ibid., No. 56.*

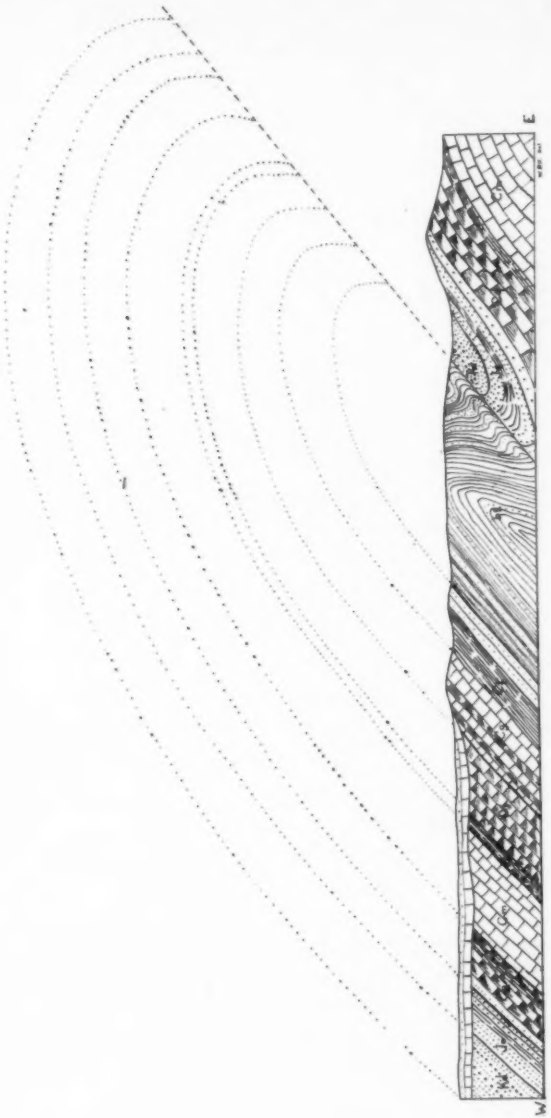

FIG. 5.—Diagrammatic section of the Lombard overthrust

The following section of the Cambrian northeast of Logan, Montana, was measured by the writer.

Dr. Peale's Nomenclature		Dr. Weed's Nomenclature	Thickness
1. Pebbly limestone	=	Yogo limestone	75 feet
2. Dry Creek shale	=	Dry Creek shale	20
3. Mottled limestone	=	Pilgrim limestone	300
4. Obolella shale	=	Park shale	280
5. Trilobite limestone	=	Meagher limestone	175
6. Flathead shale	=	Wolsey shale	450±
7. Flathead quartzite	=	Flathead quartzite	200
		Total	1,500± feet

Fossils from the Yogo limestone have been submitted by the writer to Dr. Walcott, who considers them of Upper Cambrian age, while those from the Meagher limestone are regarded by him as of Middle Cambrian age. Apparently Lower Cambrian strata are entirely absent in sections in this region. Although the boundary between the Middle and Upper Cambrian strata has not been definitely ascertained, it is likely that it comes between members 2 and 3.

Absence of Ordovician and Silurian strata.—In all of the sections studied by the writer in the Three Forks quadrangle and the neighboring district to the north, the Jefferson limestone lies in apparent conformity on the Yogo limestone without any intervening formations. The lower portion of the Jefferson limestone has been considered by Dr. Peale and others as probably of Ordovician and Silurian ages, although no fossils of those periods have been found in it. Dr. Kindle[1] has described the Jefferson limestone and its fauna and established its age as chiefly Middle Devonian with the lower part probably Lower Devonian.

In one or two good sections studied by the writer some rather poorly preserved corals were found within 25 feet of the base of the formation. These were identified as *Favosites* cf. *limitaris* Rom., which is rather common in much of the Jefferson limestone. The presence of these fossil corals is regarded as indicating the Devonian age of all of the Jefferson limestone, and since the gray Yogo lime-

[1] E. M. Kindle, *Bull. Amer. Pal. No. 20*, 1908.

stone immediately below the brown Jefferson dolomitic limestone contains Upper Cambrian fossils, the writer believes that at this contact there is a disconformity involving a hiatus in the sedimentary record of this region from the close of the Upper Cambrian to Lower Devonian time.

Further evidence in favor of this disconformity and stratigraphic overlap is brought out by the presence in sections in neigh-

FIG. 6.—Cliff of Jefferson limestone north of Crane Station

boring regions to the west and southwest of intervening strata of different lithologic character between the Yogo limestone and the Jefferson limestone, which in some cases contain fossils of Ordovician and Silurian ages. One very complete section from the Randolph quadrangle[1] in northeastern Utah, with 3,000 feet of Ordovician and Silurian strata between the Upper Cambrian limestone and the Jefferson limestone, shows very clearly the hiatus in the sections in the Three Forks quadrangle and the neighboring region to the north and northeast.

[1] G. B. Richardson, *Amer. Jour. Sci.*, XXXVI (1913), 406–416.

Devonian.—The strata of Devonian age in this region are divided into two distinct formations, the Jefferson limestone and the Three Forks formation.

Jefferson limestone: The Jefferson limestone is well described by Dr. Peale[1] as a massively bedded brown to dark-gray or black crystalline magnesian limestone with the composition of a dolomite. It is well exposed in the region under discussion in the form of brown cliffs 100 to 200 feet high (Fig. 6). In a few of the ridges

FIG. 7.—Valley in Three Forks formation, near Rekap Station

north of Three Forks the limestone is black in color, but shades of brown are the customary colors. In this region the Jefferson limestone has a thickness of about 500 feet, but it diminishes in thickness to the north and northeast, as noted in the sections in adjacent quadrangles.

Three Forks formation: Lying upon the Jefferson limestone is a series of shales and limestones which have been described by Dr. Peale[2] and named the Three Forks shales. The writer has made a careful study of this formation in all of this region, and has measured numerous sections and made extensive collections of

[1] A. C. Peale, *Bull. U.S. Geol. Survey, No. 110*, 1893, pp. 27–28.

[2] *Ibid.*, pp. 29–30.

fossils from certain of the members. A detailed account of the formation and a description of some of the fauna is in process of publication elsewhere,[1] so that only the more important points will be mentioned here.

In all of the region included in Fig. 1 the Three Forks formation shows seven fairly distinct lithologic divisions. These members are well shown in the following section of the formation made northeast of Logan near the Gallatin River.

Base of Gray Madison Limestone

1.	Yellow arenaceous limestone	30 feet
2.	Pale-yellow arenaceous shale	30
3.	Purple fissile shale	0.5
4.	Dark bluish-gray nodular limestone	9.5
5.	Fissile green shale	47
6.	Yellow crystalline limestone	15
	Gray limestone	12
7.	Yellow and orange shales	78
	Top of the Jefferson limestone. Total	222 feet

Another section farther north along the Missouri River at Rekap Station (Fig. 7), shows the variation in thickness of the different members.

1 and 2.	Yellow sandy limestone and shale	74 feet
3.	Black coaly shale	6
4.	Nodular gray limestone	7
5.	Fissile green shale and	120
6.	Gray and yellow limestone	
7.	Pebbly yellow and reddish limestones and shales	80
	Total	287 feet

It will be noted from these two sections that the members consist of limestones as well as shales, so that the term "Three Forks formation" is preferable to Dr. Peale's name "Three Forks shales."

In the region north of Three Forks and west of the Missouri River there are numerous good exposures of the Three Forks

[1] *Annals Carnegie Museum*, Pittsburgh.

formation, whose erosion has formed some rather prominent valleys, as shown on the map and in Figs. 7, 8, and 9. These valleys extend in a general north-south direction and are nearly parallel with one another. This repetition of the formation is due partly to folding and partly to faulting.

The easternmost valley eroded in the Three Forks formation is very narrow and shallow and extends northward along the eastern

FIG. 8.—Great valley in Three Forks formation. Ridge north of Three Forks

slope of the range of hills for five or six miles. The exposures are poor because the strata are vertical or overturned and much crushed by close folding.

This valley, at its southern end, swings around to the west and opens into a much larger valley, which extends to the north for about two miles. The structure which is the cause of this curious arrangement of the valley is that of a southward-pitching anticlinal fold which is overturned to the east. The strata in this very large valley are in the western limb of the anticline (Figs. 8 and 9).

West of the overthrust fault there is another valley formed in the Three Forks formation. Numerous good sections of the formation were obtained in the small tributary gullies which cut across the dip of the strata on the western sides of these valleys.

The fossiliferous members of the formation are Nos. 1, 2, 4, and 5. The general conclusions from a study of the fauna are that the formation is very late Devonian in age, as reported by Dr.

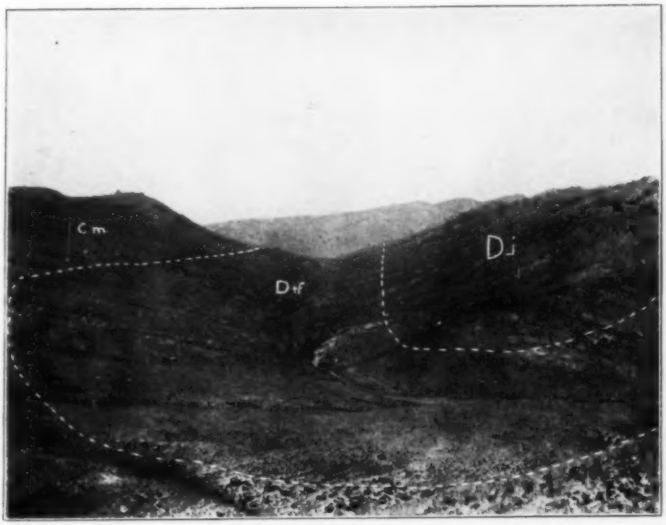

FIG. 9.—View north from southern end of valley, at apex of southward pitching anticline.

Raymond in 1907,[1] and probably represents a transition into the Mississippian in its upper part in members 1 and 2.

Carboniferous.—Throughout the mountainous part of southwestern Montana the Carboniferous formations are very prominent and form conspicuous and precipitous cliffs. In the region about Three Forks the Carboniferous strata attain a thickness of from 1,500 to 2,000 feet.

[1] P. E. Raymond, *Amer. Jour. Sci.*, XXIII (1907).

Madison limestone: The lower formation has been named by Dr. Peale[1] the Madison formation and was subdivided by him into three members; (1) the Laminated limestones at the base; (2) Massive limestone in the middle, and (3) Jaspery limestone at the top. The thickness of the Madison formation near Logan is about 1,300 feet. Although it forms conspicuous gray cliffs along the ridge west of the Missouri River, its best exposures are seen where

FIG. 10.—Missouri River in canyon in Madison limestone

the river has cut a deep canyon through it near Lombard, and also in the smaller canyon along Sixteenmile Creek, east of Lombard (Figs. 10 and 11).

A large collection of fossils was made by the writer from the Madison formation in all parts of the region. These fossils all pointed to the general Lower Mississippian age of the Madison limestone.

Quadrant formation: Lying in apparent conformity upon the Madison limestone in this region is the Quadrant formation which

[1] A. C. Peale, *op. cit.*, p. 33.

forms the upper part of the Carboniferous system. The Quadrant formation consists of two members, as noted by Dr. Peale.[1] The lower is a red arenaceous limestone overlain by bands of shale and limestone. The upper member is thinly bedded cherty limestones alternating with quartzite layers. The top of the formation is somewhat arbitrarily placed by Dr. Peale at the base of a very massive and persistent quartzite layer which is

FIG. 11.—Double horseshoe canyon of the Missouri River. View east showing Lombard Station, and mouth of Sixteenmile Creek canyon.

considered to be the basal member of the overlying Ellis formation of Mesozoic age.

The writer obtained a thickness of about 400 feet for the Quadrant north of Logan and 674 feet near Lombard. The exposure of the Quadrant formation in the canyon near Lombard is excellent, and a section was measured straight up the side of the canyon from the top of the massive cliff of the gray Madison limestone to the

[1] A. C. Peale, *op. cit.*, p. 39.

top of the massive quartzite layer which forms the rim of the canyon. The strata here strike N. 40° E. and dip 30° west (Fig. 11).

Massive pink and yellow quartzite (base of Ellis formation?)	16 feet
Quartzite and arenaceous limestone in alternating layers	60
Massive white quartzite, limonite stains	9
Limestone breccia	2
Brown arenaceous limestone	62
Grayish-brown arenaceous limestone and talus	62
Pink arenaceous limestone in cliff	36
Yellowish-red arenaceous limestone	47
Gray limestone in cliffs, shaly at base	10
Reddish shale	30
Greenish shale	57
Buff shaly limestone and talus	100
Gray bituminous limestone in cliff, with black shale layers	45
Compact gray and yellowish-brown limestone	24
Black coaly shale with calcareous bands and gypsum veins	20
Brown crystalline limestone	4
Coaly black shale, very fossiliferous	50
Yellow arenaceous limestone in cliff, some quartzite bands	46
Red shaly limestone	10
Total	674 feet

The fossils collected from the Quadrant formation indicate that it is probably of Lower Pennsylvanian (Pottsville) age. The absence of any strata referable to the Tennesseic suggests the presence of a disconformity between the Madison and Quadrant formations, although no other evidence of such a hiatus was observed by the writer.

MESOZOIC

Mesozoic formations are rather poorly exposed in this region and were not studied in detail by the writer. They consist of shaly limestones and sandstones which are generally much less resistant than the Paleozoic limestones and therefore usually occupy lowland areas. These Mesozoic strata border the Missouri Valley on both sides, and the more resistant layers form low ridges which are parallel with the trend of the higher Paleozoic hills.

In this region the Ellis formation, consisting of sandy shales and limestones with numerous layers filled with pelecypod shells, lies on the Quadrant formation with no observed discordance of dip. In the region to the south there is a well-marked reddish sandstone formation of probable Triassic age intervening between the fossiliferous Ellis and the Quadrant. Since the Ellis fossils are considered to be Jurassic in age, it seems clear that there is a disconformity in this part of the sections of this region.

Above the Ellis formation is a series of sandstones and conglomerates which have been called the Dakota sandstone by Dr. Peale, but they have recently been shown to be more probably the equivalent of the Kootenai formation of the region to the north.[1] These sandstones are therefore of probable Lower Cretaceous age. Strata of Montana and Colorado age were identified by Dr. Peale in the hills north of Logan, but there is now some doubt as to whether they can be referred to a horizon as high as that.

TERTIARY

All of the Mesozoic and Paleozoic strata were involved in the extensive orogenic movements which began at the close of the Cretaceous in this region.

The type of folding and the associated overthrust faulting has already been described in this paper. Extensive erosion reduced the region to comparatively low relief in Tertiary times. The great lowland areas were filled in by sedimentary deposits of sandstone, limestone, and volcanic ash to a great depth. The major features of the present drainage were established on this late Tertiary surface and gradually, through uplift and erosion, they were brought into discordance with the underlying structure, as is well shown by the double horseshoe canyon of the Missouri River west of Lombard.

This whole series of Tertiary valley sediments has been grouped under the heading of the Bozeman formation for convenience in mapping. Dr. Peale's name "Bozeman Lake Beds" seems no

[1] W. R. Calvert, *Bull. U.S. Geol. Survey. No. 471–E*, 1912, p. 53.

longer applicable, since they have been shown to be due to subaerial and fluviatile deposition rather than to lakes.[1]

The Bozeman formation here is chiefly of Miocene age, but in some parts of the region strata of Oligocene (White River) age have been identified.

PLEISTOCENE

The hills in this region were evidently too low for local glaciation and no signs of regional glaciation have been observed as far south as this in Montana. Gravel terraces along the rivers indicate greatly increased stream action in Pleistocene times.

IGNEOUS ROCKS

The igneous rocks in the region north of Three Forks are relatively unimportant, and are in the form of rather small intrusions of three different rock types.

GRANITE

About two miles west of Lombard, in the double horseshoe bend, the Missouri River flows for a short distance through a gorge cut in an intrusive mass of granite. Only the eastern boundary of this granite could be accurately mapped, but the approximate western limits are noted on the map.

The granite is of a light-gray color, with a medium fine texture and a somewhat porphyritic structure. The minerals recognized in a megascopic examination are white and grayish feldspar somewhat kaolinized, quartz in small amounts, and hornblendes mostly altered to chlorite. Under the microscope the feldspars are seen to be deeply kaolinized, but are chiefly orthoclase with some albite. There is a considerable amount of hornblende which is altered in part to chlorite and epidote. Some biotite and magnetite are also present.

In places this rock is almost entirely without quartz and therefore grades into a syenite. It seems to correspond closely with the description of the syenite of Yogo Peak[2] and vicinity in the Little Belt Mountains, which is noted as grading into a granite-syenite-

[1] H. F. Osborne, *Bull. U.S. Geol. Survey, No. 361*, 1909, p. 28.

[2] Atlas Folio, *U.S. Geol. Survey No. 56*, 1899.

porphyry. The granite has a well-developed set of joints which strike northeast and dip 80° east, and are about parallel with the contact with the Belt Series.

The age of the granite cannot be definitely determined at this place, but it is probably about the same age as the granitic and syenitic intrusions of the Little Belt Mountains, which are post-Cretaceous and probably early Tertiary in age.

DIORITE

Small irregular intrusive masses of diorite and diorite porphyry occur in the vicinity of Dunbar's mine, north of Three Forks. These intrusions cut the white Tertiary limestones which at this locality are considered to be of Lower Oligocene age. The diorite was observed to have nearly vertical contacts with the limestone and to occupy a much smaller area than is indicated on the geologic map of the quadrangle. The diorite porphyry seems to be a local variation in the normal diorite and its distribution can be shown only on a detailed map of the district.

Specimens of fresh diorite were obtained from the dump at Dunbar's mine. The rock from the main shaft is of medium fine texture and evenly crystalline. It consists of an even mixture of black hornblende and gray feldspar. Under the microscope the rock is seen to consist of greenish-brown to dark-green pleochroic hornblende and labradorite feldspar. Apatite, olivine, and magnetite occur in small amounts as accessory minerals. Specimens of diorite from a shaft about a half-mile to the south show a small amount of pale-pink orthoclase feldspar scattered through the rock.

Some of the diorite from a small intrusion which cuts the Cambrian formations a few miles north of the mine is distinctly porphyritic and consists of hornblende phenocrysts in rather slender crystals about a half-inch long in a gray ground-mass of plagioclase feldspar and hornblende. Magnetite and apatite occur in small amounts scattered through the ground-mass and are visible under the microscope. The rock is deeply weathered at the surface and the hornblende is mostly altered to chlorite, and the feldspar is kaolinized.

There are zones of altered rock along the contacts of the diorite and the Tertiary limestone which are well exposed about Dunbar's mine. In this contact zone are many secondary minerals which include garnets, and several copper-bearing minerals, chiefly chrysocolla, with some malachite and azurite. It is the presence of these minerals which has caused the development of Dunbar's mine. This mine was not in operation during the summers of 1912 and 1913 when the writer visited the region.

DIABASE

A rather large intrusion of diabase was observed by the writer in the extreme northern part of the region, about a mile west of Lombard. This somewhat irregular dikelike intrusion follows the plane of the thrust fault across the double horseshoe bend of the Missouri River and varies in width from 100 to 500 feet. The intrusion has produced a noticeable contact effect on the country rocks, particularly on the Cretaceous rocks on the east side, which are indurated near the contact.

The diabase is deeply weathered near the surface and has a rusty brown color. It forms a very conspicuous massive wall on the north side of the Missouri canyon, northwest of Lombard. The rock shows the ophitic structure well and is composed of augite and labradorite with some olivine, magnetite, and apatite. The age of this intrusion cannot be very definitely placed but it is clearly post-overthrusting, and therefore of Tertiary age.

SUMMARY

The contributions of this article may be summarized as follows:

1. A new geologic map of a portion of the Fort Logan region, and a revised geologic map of a part of the Three Forks region.
2. The recognition of an extensive overthrust in the northwestern part of the region, "the Lombard overthrust."
3. New facts relative to the stratigraphy of the region mapped, including the identification of a portion of the Belt Series, and the recognition of a disconformity between the Yogo limestone and the Jefferson limestone.
4. Detailed sections of some of the Paleozoic formations.
5. The igneous rocks and their manner of occurrence.

THE SKELETON OF TRIMERORHACHIS

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University of Chicago

A year ago, in a paper on the structure and habits of *Trimerorhachis*, I said, that "it will only be by the fortunate discovery of a connected skeleton that the tail, ribs, and feet will be made known."[1] Such a specimen has been discovered and skilfully worked out by Mr. Paul Miller, a photograph of which, as prepared, is shown in Fig. 1. The specimen came from the paleontologically famous Craddock Ranch, near the town of Seymour, Texas, from the same horizon as that of the skeleton of *Seymouria*, described by me a few years ago, and within a stone's throw of its locality. Its horizon seems to be nearly the same as that of the Craddock bone-bed, from which so many remarkable specimens have come. When found, the specimen was inclosed in a large, irregular nodule of bright red claystone; nothing was visible of it except the extreme tip of the nose and the base of the tail, as shown by a fracture. The under side of the nodule was smoothly convex both longitudinally and transversely; its upper side was irregular and gnarly. With this specimen, and in immediate relation with it as it lay upon the surface, were found a number of pieces, which, when fitted together, formed a block about one foot in length, which seemed to be a continuation of the tail end of the larger block. When fully prepared, however, the smaller block proved to belong to a second specimen of *Trimerorhachis*, including about twenty chiefly precaudal vertebrae, with their ribs and an imperfect femur.

The larger specimen, that figured herewith, is a nearly complete skeleton as far back as the sixth or seventh caudal vertebra. The

[1] Cope, *Proc. Amer. Phil. Soc.*, XVII (1878), 524; XIX (1880), 54; *Amer. Naturalist*, XVIII (1884), 32; Case, *Revision of Amphibia and Pisces of North America* (1911), 39, 106; Huene, *Bull. Amer. Mus. Nat. Hist.*, XXXII (1913), 372; Broom, *Anatom. Anzeiger*, XLV (1913), 73; *Bulletin Amer. Museum*, XLV (1913); Williston, *Journal of Geology*, XXI (1913), 625; XXII (1914), 160; XXIII (1915), 246.

bones, as usual in such nodules, are white and rather soft, rendering their preparation in the hard matrix difficult. It has been worked out so far as was possible without going below the surface of the bones.

FIG. 1.—*Trimerorhachis*. Specimen No. 1271, in original matrix. About one-fourth natural size.

The cadaver had come to rest in a prone position, apparently, with the head and tail directed obliquely upward, its vertebrae connected throughout in a sinuous curve, and the ribs nearly all in immediate connection with their articulating diapophyses. The right humerus had been dislocated, and lay near the posterior end of the right mandible, with its radius a little distance from its distal end. The right femur lay nearly in apposition with the acetabular part of the ilium; its distal part had been eroded away. Doubtless both the front and the hind legs of the left side are buried somewhere in the matrix.

The remarkable and wholly unexpected fact disclosed by these speci-

mens is the presence of a thin bony skin or armor closely sheathing the whole body, with the exception of the skull and clavicular girdle. As the cadaver came to rest it was immersed in the soft mud to near its middle. The skin lining the cavity thus made retains its original position. On the decay of the body, the bones fell to the lower part, closely covered everywhere by the skin of the upper part of the body. On the right side the skin had bulged outward near the middle. When first uncovered the bones were concealed everywhere by the skin. It has been removed on one side or the other to expose the bones, and between them, in a few places, to show the skin of the under side of the body, which in some places lies in juxtaposition with that of the upper side, in others separated by a thin layer of the matrix.

A dermal covering of peculiar type in *Trimerorhachis* has been several times observed by Cope, Case, and myself, but it was assumed that it covered the ventral region only, and its nature was ill understood. The present specimens show very conspicuously that it covered the whole body, with the exceptions mentioned; in the preparation of the skull not a trace of it was seen, but it is closely connected with its hind margins. In no place in these specimens does it appear to have been more than a millimeter in thickness. It is composed of slender and delicate bony fibrillae, in short pieces, and apparently in several layers. In another specimen (Fig. 3, *B*, *C*,) transverse sections show that the bony rods were in numerous layers. As these fibrillae lie in this specimen they extend through a thickness of 6 or 8 mm., and are separated from each other by intervals greater than their own thickness. It seems hardly possible that postmortem causes could have separated them so uniformly, and one must conclude that they were imbedded in a considerable thickness of integument, at least a fourth of an inch. How long any of the rods were I cannot say; the longest connected piece that I trace is scarcely a fourth of an inch. It is still possible that the sections represent the ventral skin, since nothing of their character is visible in the connected skeleton.

Notwithstanding this thickness, the skin must have been flexible to have followed every inequality of the bones below it. It was doubtless covered by a smooth epidermis.

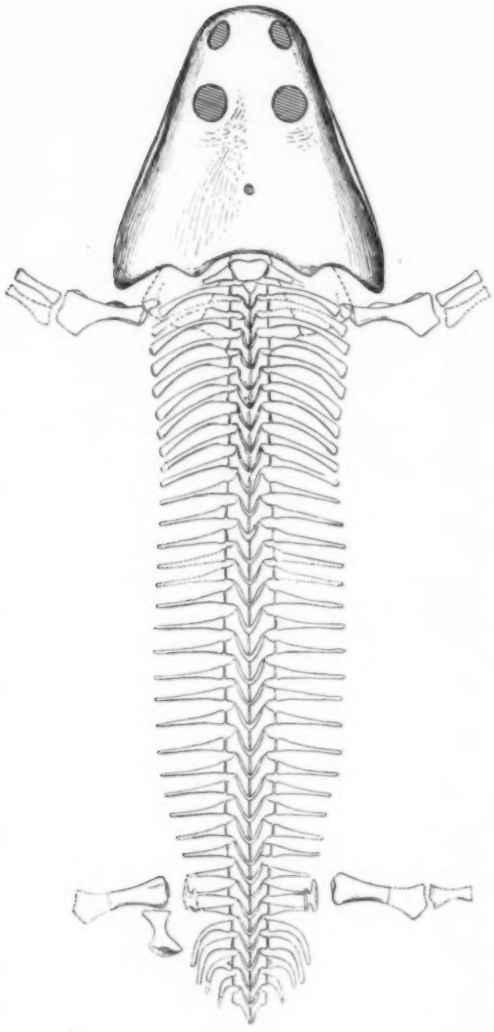

FIG. 2.—*Trimerorhachis*. Skeleton, from above, as restored from specimen shown in Fig. 1. One-fourth natural size.

Thirty-one precaudal vertebrae are visible, all in close articulation, the first one apparently with the condyle. That the vertebral column was very flexible is evident from its sinuosity as it lies in the matrix, without break. The general structure of the vertebrae is well known from isolated specimens. The pleurocentra are very small, and the intercentra are more or less U-shaped, indicating a large amount of cartilage. The spines are of nearly uniform height throughout the column, curving backward and upward, and slightly dilated at their extremities. Their height above the plane of the zygapophyses is nowhere more than 14 mm.; their width at the ends from 8 to 10 mm.

The ribs are preserved very completely in position; all have been exposed on one side or the other except two, near the middle. The first eight are the

longest, measuring about 52 mm. They also have a considerable curvature and are more or less expanded at their extremities. With the tenth or eleventh they have decreased in length to 45 mm., are less curved, and not dilated at their distal ends. Thence to the tenth precaudal they are of uniform length, more slender, and pointed. When seen from above these are all slender and nearly straight, with a moderately expanded proximal end; when turned upon their sides they are broader, somewhat curved, and with a more dilated head. Apparently some of them at least have a capitular prolongation in articulation with the intercentra. The first two precaudal ribs are slender, pointed, and entirely free, and about one inch in length.

The right humerus lies near the angle of the right mandible, as will be seen in the photograph, with its head directed forward, and with the radius somewhat removed from its distal end. There are no remains of the skin either above or below these bones. Some half-dozen skulls of *Trimerorhachis* have now been obtained with the peculiar clavicular girdle in position or nearly so, lying more or less between the mandibles posteriorly. In the drawing (Fig. 2) I have outlined in interrupted lines a clavicular girdle of another skull of the same size as the present one, in position, placing it farthest back of any of the connected specimens. The angles of the clavicles with their ascending process must indicate the position of the scapula and articulation of the humerus. The scapula is hidden and not certainly determinable in this specimen, though the edge of a protruding bone at the inner side of the distal end of the humerus, as it lies in the matrix, is probably that of the scapula. The scapula, ilium, and limbs of the left side are doubtless preserved in this specimen covered by the skin and matrix, but it has not been thought wise to sacrifice so much of the specimen as might be necessary in the search for them. In all the material from the bone-beds so far examined not a trace has been found of hand or foot bones, so that nothing can be said of their structure.

The right ilium lies in place in the matrix, in a vertical position opposite the ends of the first two presacral ribs. The bone is relatively very small, as will be seen from the figure. Among the

numerous ilia in the collections (I have seen about two score) there is no indication of roughening for attachment to sacral ribs. So far as was prudent the matrix has been removed about the ilium; there are no indications of ossified pubis or ischium. The proximal end of the right femur lies nearly in place opposite the

FIG. 3—*Trimerorhachis* Integument. *A*, surface view, No. 1271. *B*, *C*, cross-sections. No. 1208. All enlarged four times.

acetabular surface of the ilium, directed outward; its distal end has been lost from erosion of the matrix.

The looseness and small size of the ilium and the probable chondrification of the other pelvic bones are conclusive evidence, if more were needed, that *Trimerorhachis* was an exclusively aquatic animal, incapable of progression upon land. Are the undifferentiated "sacral" ribs and their lack of connection with

the ilia a primitive or an acquired character? In such animals as the mosasaurs and ichthyosaurs, when the connection of the pelvis with the sacrum was lost, the ribs disappeared; they did not revert to their primitive forms. On the other hand, *Necturus* has its sacral ribs differing from the preceding ones only in their slightly larger size, and *Necturus* certainly has not had an exclusively aquatic ancestral line from the fishes. *Necturus* also has its lower pelvic bones, as well as the mesopodials, cartilaginous, and their ancestors at some time must have had them ossified.

Not only was *Trimerorhachis* a purely aquatic animal, but, in much probability, it was also, like *Necturus*, perennibranchiate. Lying just within the angle of the left mandible there is the end of a flat bone, 11 mm. in width, with a more slender anterior end directed forward and inward, that can only be an unusually large hyoid or epibranchial bone. Back of it there is the end of what appears to be a smaller one. On either side of the first vertebrae, directed forward and outward, there are the ends of three small, rib-like bones; I do not know what they are. The length of the skull in this specimen (No. 1,271) is 165 mm.; its width posteriorly the same. The length to the beginning of the tail, allowing for the sinuosities, is 550 mm. The length of the entire animal—and the specimen is one of the largest—must have been less than one meter.

Reviews

Geologia Elementar. Preparada com referencia especial aos Estudiantes Brazileiros e á Geologia do Brazil. Por JOHN C. BRANNER. Segunda Ediçaõ, pp. 396, figs. 174. Francisco Alves e Cia, Rio de Janeiro, 1915.

Previous to the appearance of the first edition of *Geologia Elementar* in 1906, about the only textbooks in geology available to Brazilian students were those written in foreign languages and the Portuguese translation of an abbreviated text of De Lapparent, published in Rio de Janeiro in 1898, and a much earlier translation from the French which appeared in 1846. Such works, however, are founded to a large extent upon the geology of Europe and North America and thus fall short of being the most appropriate subject-matter for South American students whose greatest interest naturally centers in the phenomena of their own continent. References to familiar scenes and places are not only more impressive and instructive than citations from remote regions, but they stimulate direct observations on local formations and lead on to practical studies of home phenomena.

Recognizing the urgent need of a Brazilian textbook of geology for Brazilian students, Dr. Branner prepared this *Geologia Elementar* by drawing on the geology of Brazil as largely as possible for illustrative and descriptive matter. He was singularly qualified to do this by virtue of his very extensive field studies in that country. Few countries offer a richer field for selecting material illustrative of geologic processes than Brazil, even though great portions of it, in spite of the activity of the Brazilian survey, yet remain unexplored geologically. Its illustrative resources are attested by the success of this endeavor.

The book is divided into three sections: Part I, Dynamic Geology; Part II, Structural Geology; Part III, Historical Geology.

Part III, both on the physical side and on the biological, is almost entirely a history of the geology of Brazil. The faunas represented and discussed are, with the exception of the Jurassic, almost exclusively Brazilian. The work thus gives, in convenient form, a summary of what is known of the geological history of Brazil.

The first edition, written originally in English and translated into Portuguese by Dr. Antonio de Barros Barreto, appeared in 1906. The many additions which appear in this second edition were written directly in Portuguese by Dr. Branner, who, to his other accomplishments, adds a sufficient mastery of the Portuguese language to have become also the author of a Portuguese-English grammar which, like the *Geologia Elementar*, is recognized as a standard.

R. T. C.

Geologische Beobachtungen in Spitzbergen. Ergebnisse der W. Filschnerschen Vorexpedition nach Spitzbergen 1910. By PROFESSOR H. PHILIPP. Ergänzungsheft Nr. 179 zu *Petermanns Mitteilungen*. Gotha: Justus Perthes, 1914. Pp. 46, figs. 4.

The rocks exposed are of Jurassic and Triassic age. The former contain coal and fossiliferous beds carrying cyathophylloid corals. The interior of the island is an arctic desert. As in deserts of more temperate zones, the changes of temperature due to insolation are so great that the accumulation of scree is excessive. So much rubble falls that in some cases the mountains are completely girdled with débris even to their tops; so much so that the speed of further destruction of the mountain is greatly decreased. Built in this manner there are everywhere great débris terraces.

The west coast is bordered by a mountain chain which precipitates the moisture from the sea breezes; this makes the interior a true desert, a *hamada*. Gravel floors and dreikanter are characteristically developed. Deflation is marked, but no sand dunes are formed because the rock dust is carried onto bordering glaciers and deported. Vegetation is practically wanting; only a few valley bottoms, in the rôle of oases, become green during the short summer. The author calls this region an "arctic" desert, in distinction from the usual polar desert.

Generally the island is ice covered. The covering is controlled by the physiography; the conformity of the glacial capping to the underlying land surface is the characteristic of the typical Spitzbergen ice field. In different regions the climatic control gives rise to valley, plateau, or cap ice and slope glaciers, or to combinations of these. Slope ice forms troughs and kars. The slopes bordering the valley glacier are ice covered to the divide top. This slope ice works down the sides at right angles to the axis of the valley and to the flow of the valley glacier. It works headward by bergschrund action, while the valley

glacier deepens its bed by corrasion, until there is a decided reverse curve in the profile of the slope. The upper part is concave upward, the lower part is a convex ridge near the rim of the channel cut by the valley glacier. With decrease in abundance of snow, the slope glaciers may dwindle to bowls of snow (*wanner* and *mulden*), and by selective erosion they may become ridge-cutting cirques.

Glacial movement is essentially along shearing planes; these planes are parallel to the great friction of the glacier bed and are for that reason approximately trough-shaped. The glacier's whole movement is accomplished by means of a multitude of such planes. The planes show at the base and edges of the glaciers; on the average they are from one to two meters apart. Thus it results that, in proportion to the total amount of movement in a glacier, the shearing along each plane is very small. The blue bands are due to the regelation of the shear planes after they have been melted by the over-pressure or by friction.

Ice crystals are found in two types, those precipitated from the atmosphere and those formed by freezing waters. In one place a 20-cm. layer of névé consisted of vertical standing prisms; they were ½–1 cm. in diameter and 10 cm. long arranged in two layers of 10-cm. crystals. In the higher parts of the snow fields, beautiful rosettes of crystals bedeck the snow surfaces. The diameter of the rosettes varies from 5 to 20 cm.

Most of the evidence of Pleistocene glaciation has been obliterated by the action of insolation and frost. From floral remains there seems to have been a climate warmer by 2.5–3° C. preceding a recent uplift of about 400 feet.

T. T. Q.

Kanawha County. By CHARLES E. KREBS. West Virginia Geological Survey, County Reports, 1914. Pp. 679, pls. 32, figs. 14.

County reports have been completed for about one-half the counties of this state. Kanawha County is the first to be treated in a separate volume and its importance is such as to justify a full report. It is among the leading counties of the state in production of coal, and is rich in petroleum and building-material.

This report follows the general plan adopted in previous reports. Part I treats of the historical and industrial development and physiography. Part II takes up the stratigraphy in detail. About forty general sections of Carboniferous outcrops are given with several times that number of partial sections.

Under mineral resources the oil and gas districts are described in detail with a number of well-records from each district. Statistics on coal production place Kanawha County third in rank of the counties of the state for 1912, with a total of 5,606,522 tons. This chapter treats also of the character and distribution of the coal beds with estimates on the total supply. Clays and road and building-materials are reported in less detail. A chapter on the soils of the county is copied from the report of the U.S. Bureau of Soils on Kanawha County.

Under separate cover three maps accompany this report, a topographic map, a general and economic geology map, and a soil map. A valuable feature of the economic geology sheet is found in the structure contours. The Pittsburg coal horizon is the key formation in the western part, and the Kanawha Black Flint in the eastern. This map shows several areas in which the geologic structure appears favorable for oil and gas, that have not been prospected.

W. B. W.

Geology and Geography of a Portion of Lincoln County, Wyoming. By ALFRED REGINALD SCHULTZ. Bull. U.S. Geol. Survey, No. 543, 1914. Pp. 136.

The area described lies in the central part of Lincoln County in the extreme western part of Wyoming, east of the Salt River Range and west of Green River. Under the head of geography are discussed geographic positions, topography, altitudes, railroad and stage routes, geographic names, climate, arable land, and vegetation. The stratigraphic succession, beginning with the oldest rocks, is as follows: Cambrian, undivided (Ordovician, Silurian (?), and Devonian), undifferentiated Pennsylvanian and Mississippian, Pennsylvanian (Weber quartzite), Permian(?) (Park City formation), Lower Triassic (Woodside formation, Thaynes limestone, Ankareh shale), Jurassic or Triassic (Nugget sandstone), Jurassic (Twin Creek limestone, Beckwith formation), Upper Cretaceous (Bear River formation, Colorado group [Aspen formation, Frontier formation, Hilliard formation], Montana group [Adaville formation]), Cretaceous or Tertiary (Evanston formation), Eocene (Wasatch group [Almy formation, Knight formation, Green River formation]), Quaternary (Pleistocene and Recent).

Deposition was interrupted possibly at several times in the early Paleozoic. An unconformity based on fossil evidence, which shows the lower Cretaceous to be absent, occurs between the Beckwith formation (Jurassic) and the Bear River formation (Upper Cretaceous). Profound

folding, faulting, and erosion occurred in post-Adaville (Upper Cretaceous) time. There was slight folding and faulting after the deposition of the Almy formation (Eocene). After the accumulation of the Green River beds (Eocene) there was a long erosion interval during which the present topographic features were developed. The Eocene, Knight and Green River formations are lake deposits. The Gros Ventre Mountains and probably the Wyoming and Salt River ranges had glaciers during a part of Quaternary time. The main disturbance that gave rise to the Gros Ventre Mountains, Hoback Range, Wyoming Range, Meridian Ridge, Salt River Range, and Absaroka Ridge occurred in post-Adaville (Upper Cretaceous) time.

Coal occurs in the Upper Cretaceous Bear River, Frontier, and Adaville formations and in the Cretaceous or Tertiary Evanston formation. Oil is found in the Upper Cretaceous Bear River and Aspen formations. Gold is present in the present stream and bench deposits. The latter only are worked. Phosphate occurs in the Park City formation (Permian[?]). The sandstone of the Frontier formation (Upper Cretaceous) and also the sandstones and limestones of the older formations would make excellent building-material. Salt springs and salt deposits, as well as rock salt, occur. Salt has been produced for many years.

V. O. T.

Geology of the Standing Rock and Cheyenne River Indian Reservations, North and South Dakota. By W. R. CALVERT, A. L. BEEKLY, V. H. BARNETT, and M. A. PISHEL. Bull. U.S. Geol. Survey, No. 575, 1914. Pp. 49.

The Cheyenne River and Standing Rock Indian reservations, as here treated, include the area between the Missouri River and the one hundred and second meridian, and between Cannonball River on the north and Cheyenne River on the south. The object of the survey was the ascertainment of the coal value of the lands. The Pierre shale (Cretaceous-Montana group), which is the oldest formation exposed, covers about one-half of the area. The thickness exposed amounts to 650 feet. The Fox Hills sandstone conformably overlies the Pierre. It is the uppermost marine Cretaceous and the youngest formation of the Montana group; it is the most fossiliferous formation of the region. The Fox Hills ranges in thickness from 25 to 400 feet. The Cretaceous or Tertiary Lance formation, which consists of 700 feet of clay, sandstone, and lignitic shale, unconformably overlies the Fox Hills. Since

"the broad geologic significance" of the unconformity at the base of the Lance is not known and since the other evidence is not conclusive, the authors designate the Lance as of Cretaceous or Tertiary age. The upper 200–300 feet of the Lance is of marine origin and contains a fauna very similar to that of the Fox Hills, if not identical with it. The remainder are fresh-water beds. Tertiary Fort Union sandstone and shale succeed the Lance conformably. The terraces along the Grand River are due to deposition in a lake formed by ice which extended down the Missouri Valley damming Grand River. Glacial bowlders (from a few inches to several feet in diameter), mostly of granite, are scattered over the whole northeastern half of the area. Most of the terrace gravel and scattered bowlders are early Pleistocene, while the gravels on the Missouri River are later Pleistocene. The strata of the region dip gently to the northwest. Lignite is contained as lenses a few inches thick in beds of carbonaceous shale in the Lance and Fort Union formations. The lignite beds are described as they occur in the various townships. The lignite will probably never be mined on a large scale but will continue to be worked for local consumption. V. O. T.

The Geology of Long Island, New York. By MYRON L. FULLER. Prof. Paper, U.S. Geol. Survey, No. 82, 1914. Pp. 231, pls. 27, figs. 205, maps 2.

Long Island extends from the Narrows at the entrance of New York Harbor to a point nearly due south of the eastern boundary of Connecticut, a distance of 118 miles; its maximum width is 20 miles. The report deals chiefly with the Pleistocene geology. Long Island "may be considered as affording the type section of the earlier glacial deposits of the coastal zone"; the Iowan stage alone is absent. The literature on Long Island from 1750 to the present is summarized. Some forty pages are devoted to a thorough discussion of the physiography. It appears that Long Island Sound is a partly filled valley, cut in Cretaceous strata, produced by an eastward-draining river system. Its excavation began in post-Miocene time, was interrupted, and then completed in post-Mannetto (Aftonian?) time. The Hudson channels were formed in the Pleistocene.

The pre-Cretaceous rocks include the Fordham gneiss (pre-Cambrian), the Stockbridge dolomite (Cambrian and Ordovician), Ordovician and later granite dikes and pegmatite masses intruded into the gneiss. The beds are faulted and closely folded.

From the base up, the general sequence of the Cretaceous beds is as follows: basal clays (150 feet), Lloyd sand (85 feet), red clays (200 feet), white sand (100 feet), yellow clay (75 feet), dark clay (75 feet), undifferentiated (600 feet), buff clay (100 feet), yellow sand (150 feet), marl (10 feet). The basal clays and Lloyd sand are encountered only in wells. The surface Cretaceous beds are considerably folded (some overturned folds occur) and faulted, while at slight depths they have a gentle, even dip to the southeast. The lower beds are basal Upper Cretaceous.

There is a possibility that marls (here placed in the Cretaceous) may be Eocene, that the loose yellow quartz sand (here considered Cretaceous) overlying the marls may be Miocene; and that the white or yellow sands (here included in the Cretaceous) that succeed the Cretaceous clays may be of Lafayette age.

The Pleistocene deposits (with their probable time equivalents in parentheses) are: the glacial Mannetto gravel (pre-Kansan), the glacial Jameco gravel (Kansan), the interglacial Gardiners clay (Yarmouth), the transitional Jacob Sand and the glacial Manhasset formation (both included in the Illinoian), the interglacial Vineyard formation (Sangamon?, Iowan?, and Peorian?), the glacial Ronkonkoma and Harbor Hill moraines with associated till and outwash (all embraced in the early Wisconsin). Great periods of erosion occurred in post-Mannetto (Aftonian?) and Vineyard (Sangamon?, Iowan?, and Peorian?) times. Two ice erosion unconformities are present in the Manhasset formation, which separate the Montauk till from the Herod gravel below and the Hempstead gravel above. The various Pleistocene deposits are discussed in detail.

Stream, marine, wind, and marsh deposits constitute the Recent series.

A summary, in tabular form, is given of the principal points of geologic interest on Long Island. The geologic history is fully sketched. The remainder of the report is concerned with an estimate of the relative lengths of the Pleistocene stages and substages on Long Island, the Pleistocene and Recent orogenic movements of Long Island, the probable extension of the Pleistocene deposits (here discussed) along the New England coast (including a correlation table), the correlation of the Long Island Pleistocene deposits with the New Jersey non-glacial formations.

V. O. T.

Paleocene Deposits of the San Juan Basin, New Mexico. By W. J. SINCLAIR and WALTER GRANGER. Bull. Am. Museum Nat. History, XXXIII, Art. XXII, June 3, 1914, pp. 297–316, Pls. XX–XXVII, figs. 2.

The Paleocene Puerco and Torrejon formations are exposed along the south and southwest margin of the San Juan Basin in northwestern New Mexico. There is an unconformity, shown both by erosion and by an abrupt faunal change, at the base of the Puerco (unconsolidated clays and channel sandstones) which appears "to be the dividing line between Cretaceous and Tertiary in this region." The Torrejon succeeds the Puerco without lithologic or stratigraphic break. The boundary between the two depends on fossil evidence, and is not exactly determined. Basal Wasatch sandstone and in some places seemingly younger sandstone unconformably overlies the Torrejon. A fluviatile origin is indicated for both the Puerco and Torrejon.

Two Puerco fossil levels, to the upper of which Polymastodon is confined, were accurately located. Fossil plants were found in the Puerco. Torrejon fossils were discovered much below previously located horizons. The sections measured by the authors are compared with Gardner's Rio Puerco and Arroyo Torrejon sections. The pre-Puerco beds are, beginning with the oldest exposed, clays, conglomerate, clays, conglomerate sandstone with silicified logs and pebbles of volcanic rocks. Dinosaur remains occur in both clay horizons. "More or less of this series of beds may be correlatable with the Animas formation."

V. O. T.

Cement Materials and Industry in the State of Washington. By SOLON SHEDD. Bull. No. 4, Washington Geol. Survey. Pp. 268, figs. 10, pls. 21. Olympia, 1913.

Increasing importations of cement from California and Europe have led to investigation of the state's possibilities in cement production. The results are given in this, the fourth of a series of bulletins on natural resources. The work was directed by Solon Shedd, assistant state geologist and professor of geology, Washington State College.

More than one-third of the report is taken up with chapters on the history of the cement industry, various kinds of cements, and origin and composition of raw materials. Manufacturing processes are described briefly and there is an excellent chapter on the factors to be considered

in locating a plant. The remainder of the report takes up by counties the results of field work and contains maps of limestone and clay areas with analyses of samples from them.

In the eastern part of the states metamorphic limestones of doubtful age are found only as erosion remnants surrounded by basalts and granites. Deposits of economic importance are limited to four counties. Very little stone approaching natural cement rock is found in the state. The analyses show the limestones to be low in magnesia and silica. The latter probably averages less than 5 per cent. Analyses of adjacent clay and shale deposits are given in each case, and some estimate can be made of the possibility of proper mixtures for Portland ratios.

In western Washington sedimentary rocks predominate, but limestone is limited to a few localities in the north. Its quality is very similar to that farther east.

Taking the state as a whole, localities in which limestone and clay or shale outcrop in close proximity and favorably situated relative to transportation are few. At the time the report was published, five plants were in operation and two under construction.

W. B. W.

The Road and Concrete Materials of Iowa. By S. W. BEYER and H. F. WRIGHT. Iowa Geological Survey, Annual Report, 1913. Pp. 33–685, figs. 65, pls. 63, tables 8, maps 2.

Great development in road-building and concrete construction has led to widespread search for materials during the last decade, and justifies detailed examinations by the states of such resources. This report takes up by counties the character, amount, and availability of these materials over the entire state. Some reference is made to all the more important localities, but the records are more complete for the counties poorer in such materials than for those richly supplied.

Nearly three-fourths of the counties in the state have deposits of sand and gravel of economic importance. Gravels of two interglacial epochs are of considerable value. The Aftonian gravel is worked only in southwestern Iowa, because elsewhere it is too deeply buried. The type of locality for Aftonian is in Union County. The Buchanan gravel is available in the northeastern part of the state and is second only to the post-Wisconsin gravels as a source of road and concrete materials. It is found chiefly as a valley phase of outwash and the type locality is in Buchanan County.

Throughout the state the principal supplies are found in recent deposits in beds and terraces of the larger streams. Exceptions are found, but in general those counties crossed by drainage lines leading from the drift area have important deposits. The Mississippi River floodplain supplies the eastern tier of counties with much sand and some gravel, but similar deposits of the Missouri are more often charged with silt. In the area reached by the Wisconsin ice sheet, extensive deposits of sand and gravel are available in kames and eskers in addition to recent stream deposits.

Stone suitable for road and concrete work is limited to the eastern part of the state. In the west neither the argillaceous limestones of Pennsylvanian age nor the loosely cemented Cretaceous sandstones made good road materials. In the east and northeast, limestones are available, ranging in age from Ordovician to Mississippian. In many localities stone is not available on account of the heavy overburden of drift. Counties along the Mississippi River and its larger tributaries furnish the most favorable quarry sites.

A valuable feature of this report is found in the tables. They are compiled from data furnished by experiments on various properties important in road materials. Standard tests on cementing value, toughness, and hardness show a wide range of values. Good cementing properties may be associated with poor wearing properties or vice versa. Inferior hardness may decrease the value of materials excellent in other respects. These results show the necessity of thorough testing before final selection.

W. B. W.

Geology of the Pitchblende Ores of Colorado. By EDSON S. BASTIN. Prof. Paper, U.S. Geol. Survey, No. 90-A. Shorter Contributions to General Geology, March 17, 1914. Pp. 5, pls. 2.

The sources of uranium in the United States are given and the principal foreign occurrences of pitchblende (a complex uranate of variable composition) briefly described. Quartz Hill, which is near Central City, Gilpin County, Colorado, is "not only the one important locality in the United States where pitchblende occurs in mineral veins but one of the few in the world."

The oldest rocks of the area are included in the pre-Cambrian Idaho formation, which is mainly a quartz-mica schist. Pre-Cambrian granites

of at least two ages intrude this formation. Tertiary (probably) dikes and stocks of monzonite porphyry and bostonite porphyry cut all of the pre-Cambrian rocks.

The mineral veins, which are the products of combined fissure filling and replacement along a series of east to northeast striking fractures, traverse both the pre-Cambrian and Tertiary rocks; they are believed to be related to the monzonite intrusions. Pyritic and lead-zinc veins are represented.

A number of the specimens of the vein material show the contemporaneous origin of pitchblende, chalcopyrite, and probably minor amounts of pyrite and quartz. In other specimens the pitchblende is cut by veinlets of sulphides.

"It is believed that the pitchblende was deposited during the earlier or pyritic mineralization, that it was afterward fractured, and that the fractures thus formed were filled by sulphides of the later or lead-zinc mineralization."

The pitchblende ores apparently represent a local variation in the general sulphide mineralization of the area. They were formed under conditions of low temperature and pressure; this is true also of the Cornwall and Erzgebirge deposits. The European pitchblende occurs with cobalt and nickel minerals. No such association was observed in the case of the Quartz Hill pitchblende.

V. O. T.

Reconnaissance of the Grandfield District, Oklahoma. By MALCOLM J. MUNN. Bull. U.S. Geol. Survey, No. 547, 1914. Pp. 83.

The Grandfield district includes the southeastern part of Tillman County and the southwestern part of Cotton County in southern Oklahoma. The purpose of the report is to discuss the geology with special reference to possible oil and gas accumulations. The oldest beds exposed represent the lower portion of the Wichita formation (lower Permian). They consist of sandstone, shale, clay, and a clay-limestone conglomerate (the Auger conglomerate lentil) which is absent in places. The Grandfield conglomerate unconformably overlies the Wichita formation. It is composed of well-rounded pebbles, up to three inches in diameter, of quartz, quartzite, a few of granite, and fragments of chert, limestone, and silicified wood imbedded in a red clay-limestone matrix. It is exceedingly uniform in composition, appearance, hardness, and thickness (average 3–4 feet), is widely exposed, and "displays a structure that is

surprisingly conformable to the present topography, being high on the divides and low near the valleys." It probably will be correlated with some portion of the Seymour formation in Wichita County, Texas which is referred to the Pleistocene. The suggestion is made that the Grandfield conglomerate may not be a stream deposit.

Quaternary gravels, alluvium, dune sand, and soil mantle the older consolidated deposits.

The general structure of the Permian strata is based on the exposures of the Augur conglomerate. The most important structure is the southeast-northwest trending Devol anticline which crosses the district. To the north and parallel to this lies the Deep Red syncline. Minor anticlines and synclines are present. About one-half of the report is devoted to "detailed stratigraphy and structure of the exposed rocks by townships."

In the adjacent portion of northern Texas are located the Petrolia, Burkburnett, and Electra oil and gas fields. The "sands" are of Pennsylvanian age. Since similar beds evidently underlie the Permian in the Grandfield district, and since the structure of both places is comparable, the existence of commercial pools in the Grandfield district is very probable. Suggestions as to the location of test wells are given. The opinion is expressed that "accumulations of oil and gas in pools is due to the action of large bodies of water moving under both hydraulic and capillary pressure."

V. O. T.

Relation of the Wissahickon Mica-Gneiss to the Shenandoah Limestone and to the Octoraro Mica-Schist, of the Doe Run-Avondale District, Coatesville Quadrangle, Pennsylvania. By ELEANORA F. BLISS and ANNA I. JONAS. A dissertation (Bryn Mawr College). Pp. 64, pls. 5.

The authors conclude "that the Wissahickon mica-gneiss [pre-Cambrian] is separated from the Shenandoah limestone [Cambro-Ordovician] and from the Octoraro mica-schist [Ordovician] by a thrust fault, which has been obscured by post-Ordovician metamorphism."

V. O. T.

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